Pilot Tube Microtunneling:

Profile of an Emerging Industry

by

Vamseedhar Gottipati

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Graduate Supervisory Committee:

Jason S. Lueke, Chair
Samuel T. Ariaratnam
Allan Chasey

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ABSTRACT

Trenchless technologies have emerged as a viable alternative to traditional open trench methods for installing underground pipelines and conduits. Pilot Tube Microtunneling, also referred to as the pilot tube system of microtunneling, guided auger boring, or guided boring method, is a recent addition to the family of trenchless installation methods. Pilot tube microtunneling originated in Japan and Europe, and was introduced to the United States in the year 1995 (Boschert 2007). Since then this methodology has seen increased utilization across North America particularity in municipal markets for the installation of gravity sewers. The primary reason contributing to the growth of pilot tube microtunneling is the technology's capability of installing pipes at high precision in terms of line and grade, in a wide range of ground conditions using relatively inexpensive equipment.

The means and methods, applicability, capabilities and limitations of pilot tube microtunneling are well documented in published literature through many project specific case studies. However, there is little information on the macroscopic level regarding the technology and industry as a whole. With the increasing popularity of pilot tube microtunneling, there is an emerging need to address the above issues. This research effort surveyed 22 pilot tube microtunneling contractors across North America to determine the current industry state of practice with the technology. The survey examined various topics including contractor profile and experience; equipment, methods, and pipe materials utilized; and issues pertaining to project planning and construction risks associated with the pilot tube method.

The findings of this research are based on a total of 450 projects completed with pilot tube microtunneling between 2006 and 2010. The respondents were diverse in terms of their experience with PTMT, ranging from two to 11 years. A majority of the respondents have traditionally provided services with other trenchless technologies. As revealed by the survey responses, PTMT projects grew by 110% between the years 2006 and 2010. It was found that almost 72% of the 450 PTMT projects completed between 2006 and 2010 by the respondents were for sanitary sewers. Installation in cobbles and boulders was rated as the highest risk by the contractors.

To Mom, Dad, Dharani and Akhila

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CHAPTER 1

INTRODUCTION

It is estimated that water and wastewater utilities in the United States are responsible for approximately 800,000 miles of water pipelines and 600,000 to 800,000 miles of wastewater pipelines (USGAO 2004). The American Society of Civil Engineers reported in 2009 that the nation's water and wastewater infrastructure is in a poor state and awarded them the grades D and D- respectively, noting that many of the distribution networks are ageing and need replacement (ASCE 2009). The water infrastructure network estimated that the capital needs for water and wastewater industries together is around $740 billion for the period 2000-2019 (USGAO 2004). These statistics emphasize that there is an urgent need for replacing or rehabilitating deteriorating underground infrastructure.

The traditional method of installing underground pipelines has been to dig/trench along the alignment of the pipeline and manually install the pipes and joints. This method is often referred to as open-cut method or open trench method. For the purpose of this thesis, the method is henceforth referred to as open trench. By the virtue of its practice, open trench requires many ancillary processes such as detour of roads, storage of excavated materials on the site, backfilling and compaction, ground water management, and restoration of surfaces post the installation. These activities that are additional to the main process of installing pipes consume time, money and disrupt the movement of vehicles and pedestrians.

As an alternative to open trench, several methods have emerged over the years that minimize trench work. These technologies are together referred to as trenchless technologies. Trenchless technologies are characterized as those that minimize the need for personnel to be working in the trench below ground level. Pilot Tube Microtunneling (PTMT) is a recent entrant to the family of trenchless methods. The technology evolved combining the techniques of three other trenchless methods namely Microtunneling, Horizontal Directional Drilling (HDD) and Auger Boring. This method was initially used to install small diameter pipes and service/house laterals. However, PTMT has evolved to large diameter and main stream installations over the years. One of the main advantages of this method is its ability to perform installations at high levels of accuracy on line and grade. PTMT was introduced to the United States in the 1990s (Boyce and Camp 2008), and has since seen increase in popularity.

The means and methods of PTMT, its capabilities, advantages and limitations are well documented through published sources. However, there is little literature available on the technology's industry trends, business practices, and contractor's perspectives of the technology. With the growing popularity and acceptance of PTMT as an affordable and efficient trenchless technique, there is a need to address the above mentioned areas. It was realized that the best way to obtain this information was by contacting the contractors directly working with the technology. A survey was designed at Arizona State University in coordination with equipment manufacturers, industry consultants and contractors. The survey aimed at gathering information related to industry practices with technology, the technology's abilities and applicability, business practices, and risks, among others. Starting in September 2010, surveys were sent to PTMT contractors across the United States and Canada. Twenty two survey responses were received as on Feb 2011.

Chapter 2 presents the background for this research. Chapter 2 discusses trenchless technology in general, various methods, comparison of trenchless methods with the open trench method, background of PTMT, the variants and hybrid methods of the technology, equipment used, and case studies of three projects that were executed using a PTMT method. Chapter 3 discusses the techniques used in developing the survey and the results gathered from the compiled data. The thesis ends by presenting conclusions and recommendations for future work in Chapter 4.

CHAPTER 2

LITERATURE REVIEW

The first section of this chapter presents a general overview of trenchless technology, classification of the various technologies available, evaluation of their applicability and capabilities, and comparison of trenchless technology with the traditional open trench method. The next section discusses the origins of Pilot Tube Microtunneling (PTMT), and the technology's applicability and capabilities. The third section presents the methodology of the three variants of PTMT and discussion on the equipment used with PTMT. The third section also focuses on the methodologies of the three hybrid methods where PTMT is used in conjunction with other trenchless technologies. The fourth section discusses the advantages and limitations of the technology. The final section of this chapter presents three case studies of projects that used PTMT.

2.1 Trenchless Technology

Trenchless technologies have evolved as an attractive alternative to the traditional open trench method. The International Society for Trenchless Technology (ISTT) defines Trenchless Technology (TT) as "Methods for utility and other line installation, rehabilitation, replacement, renovation, repair, inspection, location and leak detection, with minimum excavation from the ground surface" (ISTT 2011).

It is a general agreement that TT traces its roots back to Europe. The trenchless technology industry was officially established in the United States in the year 1990 through the creation of the North American Society for Trenchless

Technology (NASTT). However, trenchless methods have been in use for over 100 years. For example, the Northern Pacific Railroad Company used pipe jacking techniques as early as the 1860s (Ariaratnam et. al. 1999). Trenchless industry has witnessed rapid growth in the past two decades. Trenchless methods have gained a share of 20% by cost in pipe installation and renewal for utility services, according to North American cost indices for the period 1988 to 1998 (Najafi and Gokhale 2005). Many new technologies have evolved over the years and rapid advancements have taken place with the existing technologies. PTMT is considered as the most recent entrant to the family of trenchless technologies. The timelines for some of the trenchless methods when they were first used are as follows: auger boring (1940), impact moling (1962), directional drilling (1971), microtunneling (1973), and pipe bursting (1980) (Ariaratnam et. al. 1999).

Trenchless methods can be broadly divided into two categories namely, new installation methods and rehabilitation methods. As evident from the names, new installation methods are those that are used for installing new pipes or conduits whereas the rehabilitation methods are those that either replace or repair existing pipes. Pipe bursting is the only rehabilitation method available that simultaneously installs a new pipe while dismantling the old pipe. Figure 1 presents the classification of various methods under the umbrella of trenchless technology. As seen from Figure 1, new installation methods can be broadly divided into two categories namely, guided methods and unguided methods. Guided methods make use of advanced technology to guide and track pipe installations, thereby providing higher accuracy on line and grade for the completed pipelines or conduits. Each of the trenchless methods is unique pertaining to its purpose, applicability and capabilities. A comparison of the capabilities of various new installation methods is presented in Table 1. Table 2 discusses the applicability of the various new installation methods in different soils conditions. As seen from Table 1, PTMT and microtunneling are the most accurate installation methods. Table 1 also shows that the drive lengths of PTMT are somewhat limited compared to the other technologies. As seen from Table 2, microtunneling is capable of working in a wide variety of soil conditions. Most of the trenchless construction methods encounter limitations when tough ground conditions such as, cobbles, boulders and rocks, are encountered.

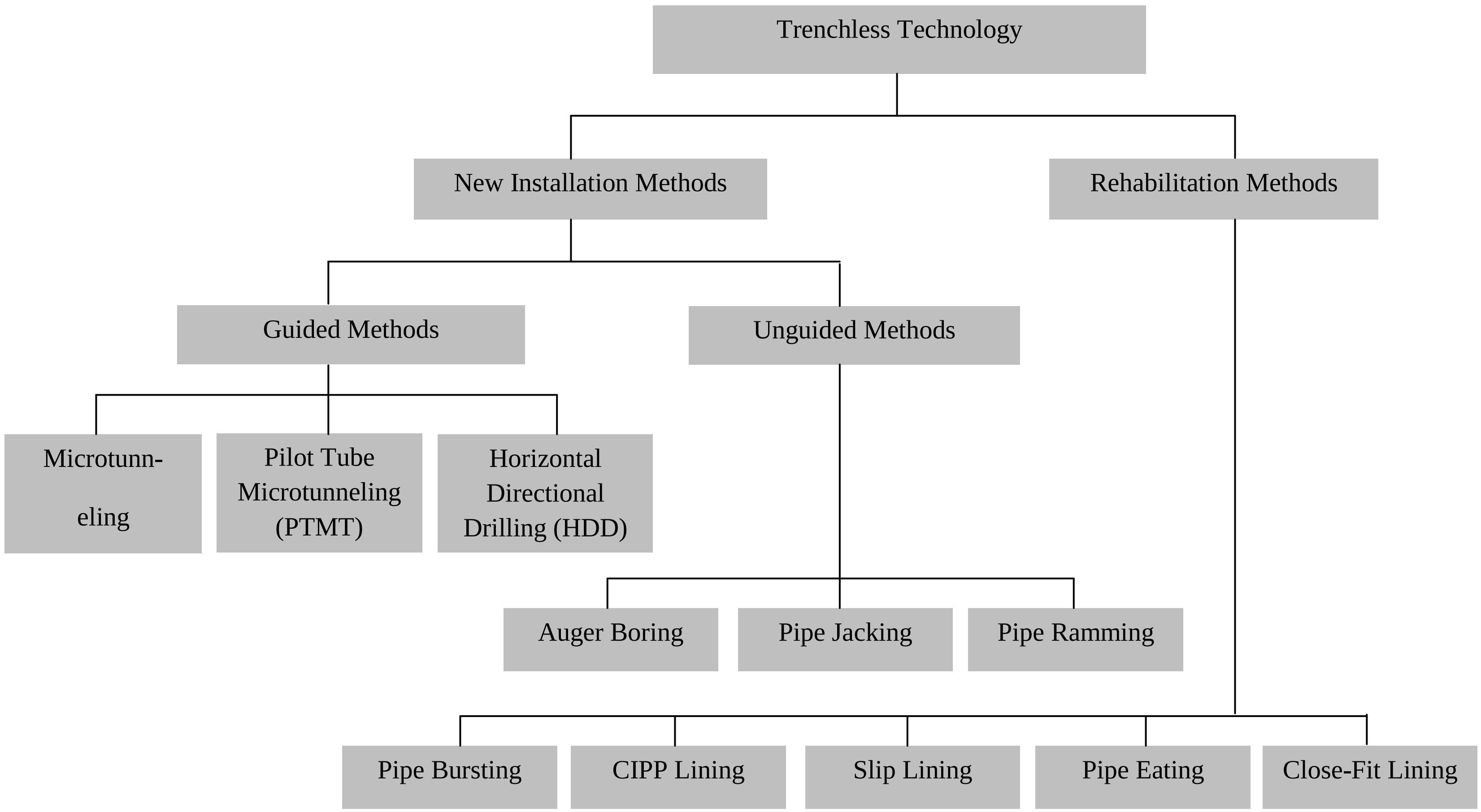

FIGURE 1. Family of Trenchless Technologies (Adapted from ISTT 2011)

TABLE 1. Comparison of the Capabilities of Various Trenchless Methods (Najafi and Gokhale 2005, Abraham et. al. 2002, Boschert 2006)

Parameter	Technology					
	PTMT	HDD	Auger Boring	Microtunneling	Pipe Jacking	Pipe Ramming
Diameter	4”-48” (Typically up to 24”)	2”-54”	8”-60”	10”-10’	42”-10’	4”-60”
Drive Length	Up to 500’ (Typically 300’)	Up to 6000’	Up to 500’	Up to 1000’	Up to 1000’	Up to 200’
Pipe	VCP, Concrete, Steel, Fiberglass	HDPE, Steel, PVC, Ductile Iron	Steel, Ductile Iron	PVC, Concrete, FRP, clay, conc.	RCP, Steel, Fiberglass	Steel
Accuracy	.25” per 300’	+/- 2% of depth of bore	+/- 1% of length of bore	Within 1”	Depends on project parameters	Depends on project parameters
Applications	Sewer, Laterals	Water, Cable, Sewer, Oil, Gas	Casing Pipe	Sewer	Casing Pipe	Casing Pipe

TABLE 2. Applicability of Various Trenchless Methods in Different Soil Conditions (Najafi and Gokhale 2005, Abraham et. al. 2002, Boschert 2006)

Ground Conditions	Technology					
	PTMT	HDD	Auger Boring	Microtunn-eling	Pipe Jacking	Pipe Ramming
Soft to very soft clays, silts and organic deposits	Yes	Yes	Yes	Yes	Not Favourable	Yes
Medium to very stiff clays and silts	Yes	Yes	Yes	Yes	Yes	Yes
Hard Clays and Highly Weathered Shales	Yes	Yes	Yes	Yes	Yes	Not Favourable
Loose sands above watertable	Yes (w/ lubricant)	Yes	Not Favourable	Yes	Not Favourable	Yes
Medium to dense sand below water table	Not Favourable	Yes	No	Yes	No	No
Medium to dense sands above water table	Yes	Yes	Yes	Yes	Yes	Yes
Gravels and Cobbles less than 2”-4” dia	Yes	Not Favourable	Yes	Yes	Yes	Yes
Soils with significant cobbles, boulders, larger than 4”-6” diameter	Not Favourable	Not Favourable	Not Favourable	Not Favourable	Not Favourable	Yes
Weathered rocks, marls, chalks, and firmly cemented soils	Yes (w/ air hammer)	Yes	Yes	Yes	Not Favourable	Not Favourable
Slightly weathered to unweathered rocks	Yes (w/ air hammer)	Not Favourable	Yes	Yes	No	Not Favourable

2.1.1 Trenchless Versus Open Trench

Trenchless technologies require significantly less trench work and surface footprint compared to open trench and hence offer numerous advantages. In urban settings, construction activities may lead to inconvenience and added costs to the public, which are often characterized as “social costs”. Social costs are defined as those that are neither direct nor indirect costs to the parties in a contractual agreement (Allouche et. al. 2000). Savings in social costs is one the prime advantages of trenchless technology over the traditional open trench method. Government agencies and utility owners are beginning to realise the advantages offered by trenchless technologies and favouring their selection over the open trench method (Bruce 2002). This section presents a comparison between trenchless technology and the traditional open trench in the five categories including: 1) surface disruption; 2) safety; 3) damages to infrastructure; 4) environmental issues; and 5) project costs.

Surface Disruption

Trenchless technologies offer numerous advantages over the open trench method in this category. In urban settings, pipelines are commonly located beneath the roadways. Advances in trenchless technology have facilitated installations with minimum surface disruption and thereby minimizing the disturbance caused to businesses, pedestrian and vehicular movement, and local residents. When using open trench method, due to larger surface space requirements the roads are narrowed down leading to traffic congestion. Detours for roads are commonly required with trench work, which cause inconvenience, loss of time, and added fuel costs. Businesses around the open trench construction sites may lose revenues from loss of customers due to inconvenient access, construction noise and clutter (McKim 1998). The costs arising out of the above discussed issues are all part of social costs.

Safety

The accident rate for trench work is about 112% higher than that of general construction (Everett and Frank 1996). Trenchless technologies requiring significantly less trench work increase the safety factor for the crews. Also, there is an increased probability for motor vehicle crashes in construction work zones. For the year 2009, 2% of all motor vehicle crashes in the United States have occurred in a construction or maintenance zone (NHTSA 2010). When using trenchless technologies, the work zones occupy less area because of the lesser trench work involved. Therefore, it can be asserted that installations using trenchless technologies are much safer to both the crews and community when compared to open trench method.

Damages to Infrastructure

As pipelines are often located beneath the roadways, employing open trench method on such cases involves digging up the pavements followed by restoration. It was observed that the life expectancy of pavements is reduced by up to 60% with dig-up repairs (Najafi and Gokhale 2005). Since trenchless methods require only minimal excavation, this issue could be largely avoided. Compaction of back fill is a necessary process with open trench construction to maintain ground stability. However, there may be long term affects and chances of ground movement due to settlement. Also, the process of compaction may affect existing utilities near the project. Settlement is relatively minimal with trenchless methods when compared to open trench. However, there is a possibility of ground disturbance when installing large diameter pipes using technologies like auger boring.

Environmental Issues

Contaminated soils are frequently encountered when performing excavations. These soils need to be properly disposed in compliance with the law. The needs arising out of such activities may result in additional costs and loss of productivity. The advantage offered by trenchless technologies in this respect is that they require significantly lesser excavations and therefore the amount of contaminated soils, if encountered, is relatively less in volume. During open trench construction large amounts of soil is stockpiled on the site, before being backfilled, possibly resulting in fine soil particles becoming airborne and polluting air. Rain or water encountered during this process might result in soil erosion and contaminated soils runoff into water bodies causing water pollution.

Trenchless methods, when compared to open trench construction, may realize reduction in airborne pollutant emissions due to shorter project durations, less use of construction equipment and less disruption to vehicular movement. Additionally, projects executed using the open trench methods require transporting considerable amounts of trench excavation, support and restoration materials, resulting in greater emissions. Rehan and Knight (2007) determined that it may be possible to achieve a 78 to 100% reduction in greenhouse gas emissions by employing trenchless methods over open trench construction. In a case study performed by Ariaratnam and Sihabuddin (2009), it was observed that a project executed using open trench construction produced approximately 79% higher emissions over a similar project completed using pipe bursting, a trenchless rehabilitation method. It can therefore be concluded that trenchless methods are more environment friendly.

Project Costs

Conventional open trench might be an expensive option compared to trenchless technologies when installing at greater depths below the water table (Neider 2006). When installing in such conditions with the open trench method, dewatering solutions are necessary throughout the alignment which increase projects costs. As seen from Table 2, there are many trenchless construction methods that can perform in soils below the water table and may offer cost advantages. In a research conducted by Zhao and Rajani (2002), it was observed that microtunneling is much more expensive than open trench for all diameter ranges. It was also seen than open trench is a cheaper option, compared to microtunneling, HDD, and pipe jacking, in the large diameter range (38 inch to 72 inch). This may be due to the complexity involved in such projects. Even though trenchless methods may appear to be a cheaper option because of less surface disruption, few studies have verified this claim (Rayman et. al. 2008). It may be concluded that costs are highly project specific and both open trench and trenchless methods have their cost advantages depending on the project conditions.

2.2 Introduction to Pilot Tube Microtunneling (PTMT)

Pilot Tube Microtunneling (PTMT), also referred to as pilot tube system of microtunneling, guided auger boring and guided boring method, originated in Japan and Europe two decades ago as a way to install 4 and 6 inch house connections (Boschert 2007). Guided auger boring is defined as "Auger boring systems which are similar to microtunneling, but with the guidance mechanism actuator sited in the drive shaft (e.g. a hydraulic wrench which turns a steel casing with a symmetric face at the cutting head). The term may also be applied to those auger boring systems with rudimentary articulation of the casing near the head activated by rods from the drive pit" (NASTT 2000). It was first introduced in the United States in 1990s (Boyce and Camp 2008), and has since seen increase in capabilities and popularity. PTMT was patented in the United States under the name "Apparatus and Method for Pilot-Tube Guided Auger Boring" in 2001 by David J. Monier and Francis E. Robinson, both from Perryville, Missouri (Monier and Robinson 2001).

PTMT evolved from a combination of three other existing trenchless technologies namely microtunneling, horizontal directional drilling (HDD) and auger boring. The installation process of PTMT resembles that of HDD through the use of pilot boring followed by reaming and product pipe installation. Both PTMT and HDD use a slant faced steering head for directional control. PTMT adopts its accurate guidance system from microtunneling, although in a slightly different format. Further the technology is similar to auger boring in the use of a jacking system and auger flights for spoils removal. Similarities between PTMT and the three ancestral technologies are concurrently discussed in Section 2.3 while presenting the methodology. For information related to the methodologies of the technologies ancestral to PTMT, refer to: HDD (Ariaratnam and Allouche 2000); Microtunneling (Powers et. al. 2007; Myers et. al. 1999); Auger Boring (Iseley and Gokhale 1997).

The initial capabilities of the technology were in the range of 4 inch to 12 inch outside diameter pipes with single drive lengths up to 250 feet (Boschert 2007). The technology can now install pipes up to 48 inch outside diameter with drive lengths in the range of 400 feet (Haslinger et. al. 2007). Pilot Tube installations as long as 580 feet in a single drive has been completed successfully as reported in Chapter 3. Accuracy in line and grade of 0.25 inch is possible on installations up to 300 feet in length (Abbott 2005). Better optical guidance systems and power hydraulics in the jacking frames have made larger diameters and drive lengths possible.

The technology can perform in a variety of soils conditions though cobbles and boulders might pose some difficulties. The technology can be conveniently used in competent soils above the water table (Ramos and Stephl 2008). PTMT has been successfully used in weak soils with zero blow count. As seen from Table 2, the technology's performance is marginal when gravels and cobbles of greater than 4 inch diameter are encountered. Recent developments such as lubricants for loose sands, water control reaming heads for wet sands, and air hammers for solid rock have increased the possibilities for different soil conditions (Boschert 2007). The City of Atlanta completed drives of PTMT, as part of its Combine Sewer Overflow Remediation Plan, in solid granite using a combination of PTMT, air hammers and compressors (Bruce 2008).

The technology can install a variety of jacking pipe materials such as concrete, clay, fiberglass, polymer concrete, and steel. Being a jacking technology, PTMT favors the use of pipes that can withstand the high jacking loads. Vitrified clay jacking pipe is predominantly used in PTMT installations for the various advantages it offers such as high compressive strength, leak free joints, long useful life, corrosion resistance, and affordability in the typical product pipe section range of 3.3 feet to 6.6 feet (Bruce 2002). Fusible pipe has also been successfully pulled back from the reception shaft behind both the pilot as well as the temporary casings.

2.3 PTMT Methodology and Equipment

The three most common variants of PTMT are: 1) Two-Step Method; 2) Three-Step Method; and 3) Modified Three-Step Method. There is little difference in the site preparation and equipment setup among the three variants. The first Part of this section details the site preparation phase of a typical PTMT project. The next Part presents an in-depth discussion of the methodologies of the variants of the technology along with presenting details of the equipment used.

2.3.1 Site Preparation and Set-Up

Site preparation for a drive of PTMT, begins by excavating jacking and reception shafts. PTMT method requires jacking and receiving shafts for each drive. As seen from Table 1, the typical drive lengths for PTMT are in the 300-400 feet range. Since typical pipe installation projects are much longer, PTMT projects are often executed in multiple drives. It is common for the receiving shaft of one drive to act as a jacking shaft for another. If the project layout permits, two drives can be performed from the same jacking shaft simply by rotating the equipment and boring in the opposite direction. Since the jacking machines used on PTMT installations are compact, the shafts are relatively small when compared to microtunneling and pipe jacking. Shafts can either be rectangular or circular depending on the project considerations. The jacking and reception shafts are most commonly round, with the minimum size of jacking shafts being 8 feet in diameter and reception shafts being 6.5 feet in diameter (Ramos and Stephl 2008). The shafts are most commonly drilled by a vertical boring machine and a pre-built corrugated metal structure is lowered to support the earth loads, as shown in Figure 2.

FIGURE 2. Placing the Pre-Built Shaft Support (Boschert 2006)

When water is encountered during shaft construction or when it is determined that the ground is unstable, concrete pads and thrust blocks are poured at the bottom of the jacking shaft to withstand stresses from the heavy jacking system and prevent any potential settling (Fisher 2003). After the construction of the shaft is complete, the jacking machine is lowered into the jacking shaft and set up rigidly. A guidance system is then set-up and the jacking frame is oriented to match the desired line and grade using the digital theodolite of the guidance system. With the site preparation and equipment set complete, the first step of installing pilot tubes can begin.

2.3.2 Three-Step Method

Three-step method is the traditional form of PTMT. The method involves boring a pilot hole, installing the auger casings and replacing the casings with the product pipe.

First Step

First step, common to all the three variants of PTMT involves drilling a pilot bore hole using a steering head trailed by pilot tubes. The process begins by attaching a steering head to a pilot tube section and mounting the assembly on the jacking frame. The operator adjusts the steering head and the jacking frame with the assistance of the guidance system to match the desired line and grade. Initial setup prior to drilling is very important as the accuracy of the final pipeline depends on the accuracy of the pilot bore. Pilot boring is started by thrusting the steering head into the ground. Once the steering head and the first pilot tube section are inside the ground, thrusting is stopped and the jacking machine is retracted to its original position. A new section of pilot tube is attached to the trailing end of the pilot tube section already inside the ground. The pilot tubes are fastened to each other using clips or their internal threading. The boring is continued and the process of attaching new pilot tube sections is repeated until the steering head reaches the reception shaft. The first step of the three-step method is depicted in Figure 3.

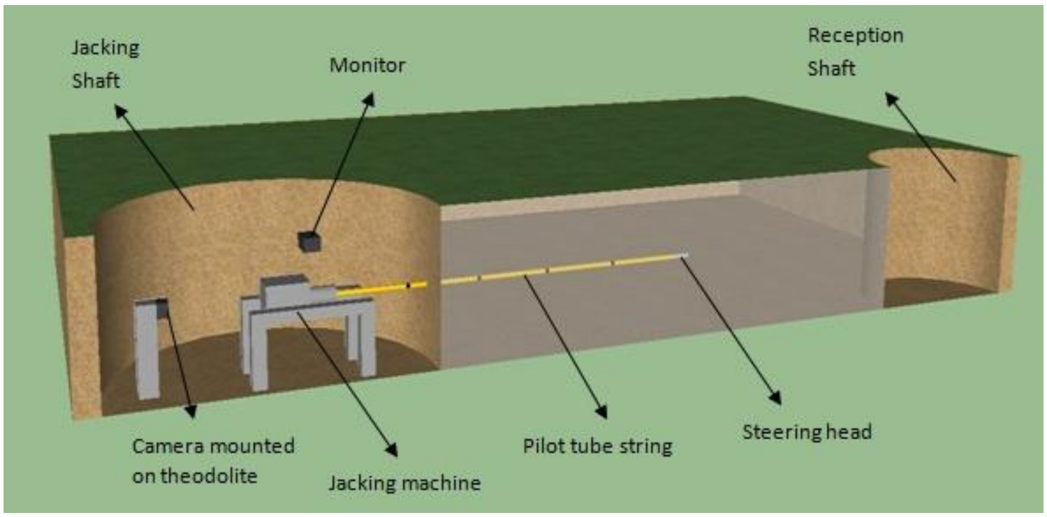

FIGURE 3. First Step of the Three-Step PTMT Method

Torque and thrust are transferred to the steering head through the surface of the pilot tube string. Steering head and the pilot tubes advance only by thrusting and no rotation is used unless variations in the alignment are observed. Pilot tubes advance by displacing and pushing the soil around them. Hence, no soil is trapped inside them and the need for soil removal does not arise. Since the diameter of the pilot tubes is very small, no significant ground movements are observed during pilot boring. The pilot tubes, similar to the casings and product pipe sections, are typically 3.3 feet or 6.6 feet in length (Boschert 2007). The typical diameter of pilot tubes is 4.25 inch (Force et. al. 2005). Pilot tubes are stacked at the site location in a manner depicted in Figure 4, and transferred into the jacking shaft one after one as the pilot bore progresses.

FIGURE 4. Pilot Tubes Staged on the Site (Ramos 2009)

The guidance system used in PTMT is inspired from microtunneling. While the guidance system used in microtunneling contains the light source in the jacking shaft and the camera inside the boring machine, the places are reversed for the guidance system used with PTMT where the light source is inside the steering head and camera is in the jacking shaft. PTMT's guidance system comprises of a LED illuminated target, digital theodolite, camera and a monitor screen. The LED target is mounted on the inside of the steering head. Prior to pilot boring, a theodolite is setup in the jacking shaft at an orientation that exactly matches the expected line and grade of the product pipe.

A camera is mounted on top of the theodolite and focused on the centre of the target. The LEDs on the target form two concentric circles and a radial straight line, as seen from Figure 5. While the circles are helpful in identifying the variations in line and grade of the steering head, the straight line is used to identify the orientation of the slant face of the head. The hollow passage of the pilot tube string serves as an optical path for the guidance system. One of the factors affecting the length of the drive is the visibility through the pilot tube string. Visibility through the pilot tube stem could be affected due to condensation within the pilot tube cavity. This problem could be easily overcome by using a dry inert gas (Boyce and Camp 2008).

FIGURE 5. LED Illuminated Target Mounted Inside the Steering Head (Boschert 2006)

The operator continuously monitors the position (with respect to the line and grade axes) and orientation of the steering head from the camera output displayed on the monitor. This guidance system of continuous monitoring is necessary to install pipe precisely on line and grade. The guidance system with its various components is displayed in Figure 6.

FIGURE 6. Guidance System with its Components (ISTT 2011)

The slant faced steering head used in PTMT is inspired from HDD. The slant face is an important feature of the steering head as it is helpful in correcting variations in the alignment. If any variations in the line and grade are observed, thrusting is stopped. The steering head is then rotated to a necessary clock position and the pilot stem is pushed back to alignment.

Several different types of steering heads with different slant angles are available. The supporting equipment for the steering heads include: a connecting adapter, an adapter to allow fluid and air flows when using dual walled pilot tubes, and a target holder. Different types of steering heads along with the supporting equipment are displayed in Figure 7.

FIGURE 7. Various Types of Steering Heads and the Supporting Equipment (Akkerman 2010)

The pilot tubes could either be single or dual walled. Dual walled tubes are used to pump lubricant to the steering head through the cavity between the two walls. Lubrication reduces the friction between the steering head and the soil making greater drive lengths possible. In case of dual walled pilot tubes, the thrust is transmitted to the steering head through the outer walls, while the inner walls are used for transferring torque.

The jacking machines used for PTMT are similar to the ones that are used for auger boring. Jacking machines are also known as Guided Boring Machines (GBMs). The jacking machine determines the jacking force/horizontal pressure, rotational torque and penetration rate of the boring process on a project. Since PTMT method is primarily used on installations of small diameter pipes, the required jacking forces are not as high when compared to microtunneling. Hence jacking machines with significantly lower capacity are used on PTMT method. Therefore the jacking machines, as shown in Figure 8, are very compact (Monier and Vedder 2000). A single jacking machine is capable of performing all the three-steps on a typical PTMT method – drilling pilot tubes, jacking auger casings and jacking final product pipe.

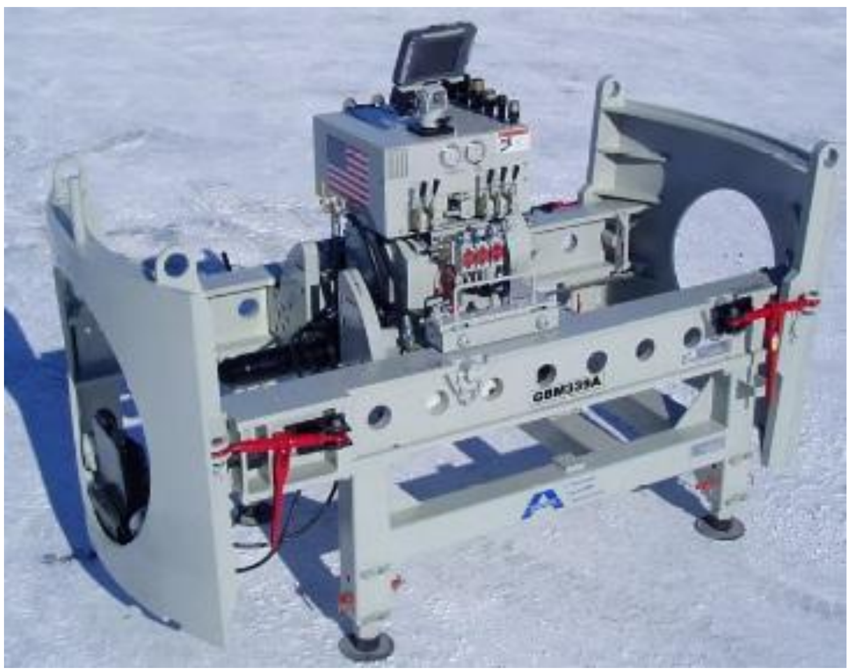

FIGURE 8. Jacking Frame (Akkerman 2010)

The selection of a jacking machine is governed by the following considerations: length of bore, diameter of the final pipe and expected resistance from the ground. Jacking machines use a hydraulic motor as a source for thrust. These motors are powered by external power units called power packs that are stationed on the surface above the jacking shaft. Jacking machines are equipped with hydraulic pressure gauges to monitor the thrust and rotation pressures at any given time. Any changes in the soil conditions, as the pipe installation is in progress, could easily be identified using these gauges. Akkerman, Bohrtec and Wirth are the major manufacturers of jacking machines and other ancillary equipment. Akkerman manufactures jacking machines (GBMs) especially for the PTMT method. Akkerman's guided boring machines are capable of installing 4-48" outside diameter pipes in displaceable soils under 50 blow count (Akkerman 2010).

Pilot bore is complete after the steering head reaches the reception shaft where it is retrieved. The guidance system may now be removed as it is no longer required. At this point of the installation, a survey can be performed on the pilot tube at the reception shaft to verify line and grade accuracy of the initial survey and setup. If a survey or setup error is found, the pilot tubes can be retracted and reinstalled before proceeding to the second step of the installation.

Second Step

The second step in the three-step PTMT method, as shown in Figure 9, involves reaming the pilot hole to a diameter slightly larger than that of the final pipe, while simultaneously installing auger casings. The purpose of this step is to increase the diameter of the pilot bore. The second step begins by attaching the rear end of a reaming head or a cutter head to an auger casing, as shown in Figure 10. This assembly is then fixed on the jacking frame. The front end of the reamer is attached to the last section of the pilot tube inside the ground using a special adapter. The auger, coupled inside the first casing, is fastened to the drive swivel in the jacking frame. The reamer is advanced by a combination of thrust and torque. Thrust force and torque are transferred to the face of the reaming head through the surface of the augers. After the reamer and the first auger casing are totally inside the ground, the jacking frame is retracted back to its original position. A new casing is lowered into the jacking shaft and attached to the jacking frame on one end and the other end is attached to the casing which is already inside the ground. The auger inside the new casing is attached to the previous auger on one end and the other end is attached to the drive swivel on the jacking machine. The boring is continued and the process is repeated until the casings replace all the pilot tubes.

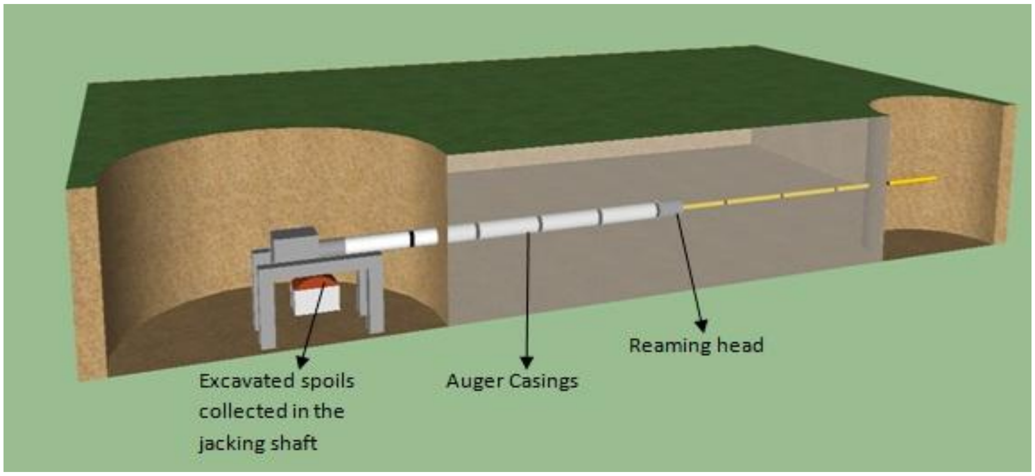

FIGURE 9. Second Step of the Three-Step Method

Augers are rotated to transport the excavated soil back to the driving shaft. The outer diameter of the rear end of the reamer is slightly larger than that of the auger casings. This feature creates an “overcut” to reduce the friction between the casings and the soil. Overcut eases the ground resistance on the auger casings, thereby lowering the jacking forces. Typically, a 1.25 inch overcut is recommended (Ramos 2009).

FIGURE 10. Reaming Head Welded on the Auger Casing
(Anderson 2008)

The pilot tubes are retrieved at the reception shaft as the casings are advanced. The augers that are connected to each other, forming an auger string continuously transport the excavated soils back to the jacking shaft. However, once the installation of casings is complete soils can be transported to the reception shaft by rotating the augers in the opposite direction. Spoils are removed from the jacking shaft by using either a muck bucket or a vacuum truck (Sewing et. al. 2009). A lubricant may be used to reduce friction between the casings and the soil. Lubricant can either be applied before each casing is dispatched for drilling or continuously using pipes that travel along the inside or the outside of the top of the casings.

Auger casings used with PTMT are typically 3.3 or 6.6 feet long and are made from steel (Monier and Vedder 2000). Auger casings are available in a variety of diameter sizes. Steel is the material of choice for the auger casings, as the casings should be able to withstand the potential damage caused by augers that rotate inside them and also withstand the high jacking forces that are required to cut through the soil. Auger casings are stacked on the site, as shown in Figure 11, and transferred to the jacking shaft one after one as the second step is in progress.

FIGURE 11. Auger Casings with Augers (Wallbom and Huber 2008)

As PTMT method is primarily used on installations of small diameter pipe, not all product pipe materials might be able to withstand the high jacking forces required to cut through the soil. Hence the use of auger boring technique, inspired from the auger boring method, provides a flexibility of using a variety of pipe materials for the final pipeline as the soil would have already been excavated by the final stage of installation and thereby needing jacking forces just enough to push out the casings.

Third Step

The third step, as depicted in Figure 12, involves replacing the previously installed auger casings with the product pipe. The lead end of first pipe section is attached to the rear end of the last casing using a special adapter. Pipe sections replace the auger casings in a similar fashion as the auger casings replace pilot tubes in the second step. However, there is no excavation involved in the third step of the three-step method as the product pipe is either equal or smaller in diameter than the auger casings. The auger casings are retreived from the reception shaft as the pipe sections are advanced. Only those pipe materials that can withstand high jacking forces could be used in this step.

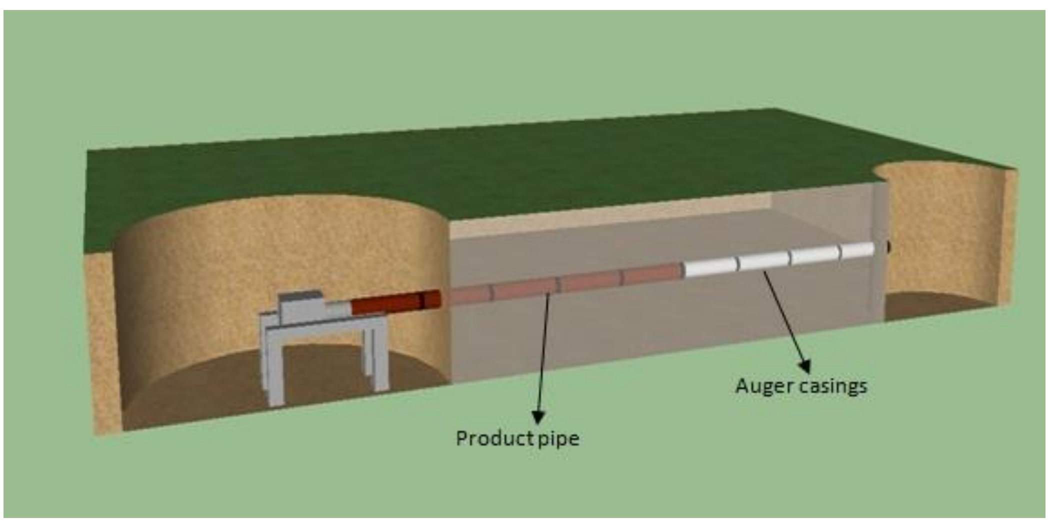

FIGURE 12. Third Step of the Three-Step Method

2.3.3 Two-Step Method

The first step of the two-step method is the same as that of the three-step method. The second step in this method combines the second and third steps from the three-step method. Hence the discussion in this Part is only focused on the second step of two-step method. In the second step, sections of product pipe are simultaneously installed as the reamer advances through the ground replacing the pilot tubes installed in the first step. Step 2 of the two-step method is depicted in Figure 13.

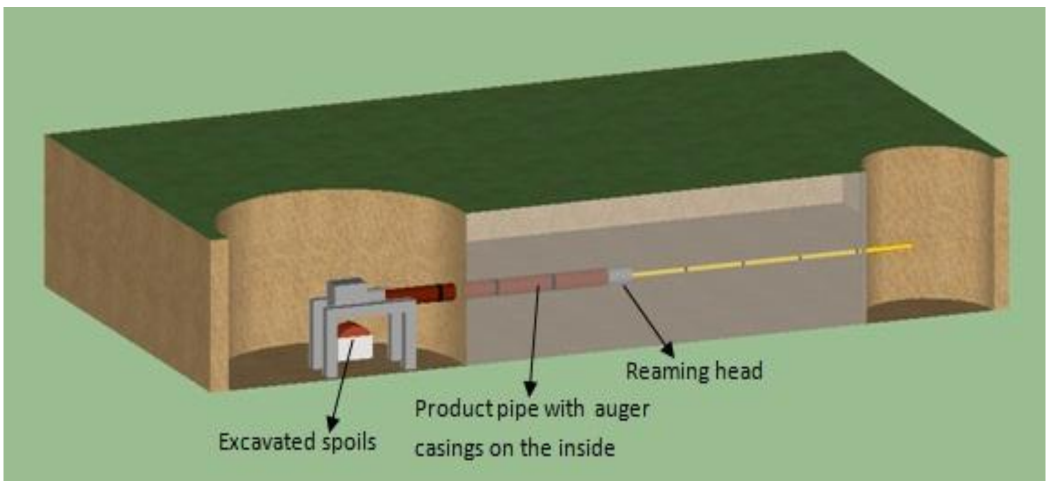

FIGURE 13. Second Step of the Two-Step Method

The second step begins by mounting a reaming head and a product pipe section assembly on the jacking frame. Each product pipe section contains an auger casing, coupled with augers on the inside of the casing, as shown in Figure 14. A special reaming head, different from the ones used with the three-step method, is used to funnel the excavations into the auger casing. After the reaming head and the first section of the product pipe are completely pushed into the ground, the jacks are retracted back to their original position. A new section of product pipe, coupled with auger casings on the inside, is then lowered into the shaft and set up on the jacking frame. The new pipe section is connected to the trailing end of the pipe section already inside the ground. Two additional sets of connections, for the auger casing and the auger, also need to be made for this new section. The process is repeated until the pipe sections replace all the pilot tubes. After the product pipes are installed, auger casings are retrieved either from the jacking shaft or the reception shaft.

FIGURE 14. Auger Casings Inside the Product Pipe Sections

The prime advantage of using this method over the three-step method is that the contractors are able install multiple pipe diameters using the same set of auger casings. However, as the diameter of the product pipe increases, it may be difficult for the smaller auger casings to transport large quantities of excavated material (Sewing et. al. 2009).

2.3.4 Modified Three-Step Method

The modified three-step method makes use of a powered cutter head (PCH) or a powered reaming head (PRH). This variant is the newest addition to pilot tube methods (Boschert 2007). The first two-steps for this method are the same as that of the three-step method. Therefore the discussion presented in this Part only focuses on the third step of the modified three-step method.

The third step for this method is similar to that of the three-step method, except that this method uses a PCH or PRH as a lead end of the product pipe section chain, when replacing the auger casings. A powered head is used to increase the diameter of the bore hole further to match that of the larger product pipe. After the second step is complete, a PCH or PRH is lowered into the jacking shaft and set up on the jacking frame. The powered head is then attached to the rear end of the last auger casing already inside the ground. Further the powered head is also attached to the auger chain inside the installed casings. The powered head is advanced by the product pipe while it cuts around the auger casings. The newly excavated soil by the powered head is transported to the reception shaft through the previously installed auger casings from the second step. The powered head reverses the rotational direction of the augers for this purpose. The third step is depicted in Figure 15.

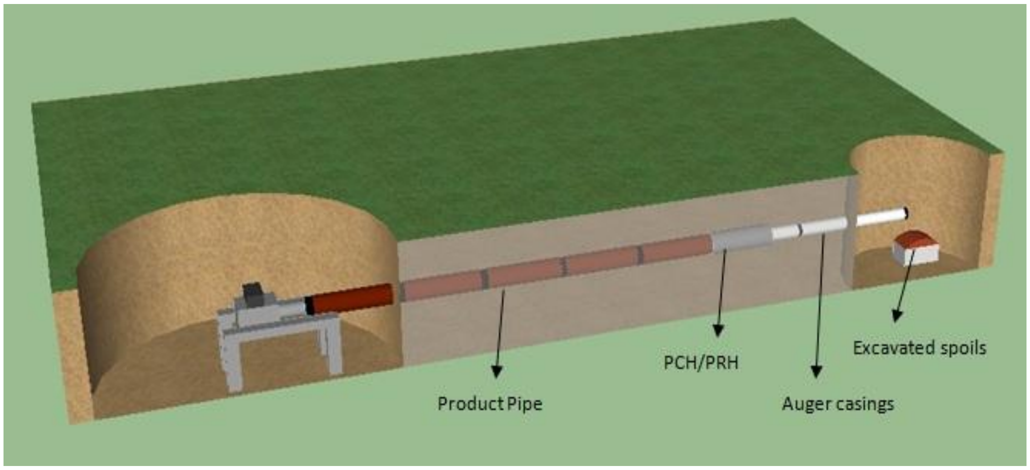

FIGURE 15. Third Step of the Modified Three-Step Method

The power heads are hydraulically powered by hoses that run from the jacking shaft to the head through the product pipe sections. Lubrication is supplied to the face and rear of the powered heads through separate hoses that run in parallel to the power supply hoses. Lubrication on the face of the head softens the soils for easier excavation, while the lubrication at the rear of the head reduces the jacking forces needed to advance the product pipe. When using a powered unit, the product pipes are typically staged with the needed hydraulic hoses running through them at the surface to prevent having to stop and reconnect during installation.

While both PCH and PRH are designed to upsize the diameter of the bore hole, a significant distinction between the two is that the powered reaming heads are not equipped with cutting bits on the face unlike powered cutting heads. Powered reaming heads are equipped with a cutting ring to perform excavations. Akkerman manufactures PRH equipment that can work with 14”, 16” and 18” outer diameter pipes. The PCH equipment range for Akkerman products is 20” to 44” outer diameter. Increaser kits are also available from Akkerman that increase the PCH range to 48” (Akkerman 2010). PCH and PRH heads are depicted in Figures 16 and 17 respectively.

FIGURE 16. Powered Cutting Head (PCH) (Akkerman 2010)

FIGURE 17. Powered Reaming Head (PRH) (Akkerman 2010)

2.3.5 Hybrid Methods

While PTMT is designed as a standalone pipe installation system, the technology is often used in conjunction with other trenchless technologies. The three main hybrid versions of PTMT are, PTMT-Auger Boring, PTMT-HDD and PTMT-Pipe Ramming. The idea behind such hybrid methods is to establish an accurate alignment using PTMT's guided pilot boring followed by product pipe installations by the other technology.

PTMT-Auger Boring

The first step in the PTMT-Auger Boring hybrid method is guided installation of pilot tubes similar to conventional PTMT. The PTMT machine is attached to the auger boring rails at the outset using special adapters. Once the first step is complete, the PTMT machine is removed from the jacking shaft and replaced with a auger boring machine. A reaming head is attached to the last section of the pilot tube assembly. Now that the line and grade of the installation are established, the auger boring machine tunnels the augers into place while the pilot tubes are retrieved from the reception shaft. Typically auger boring installations could be realized at an accuracy of $\pm$1% of the length of the bore (Najafi 2004). The low level of accuracy makes installing larger diameter pipes at longer drive lengths impractical, especially in congested urban settings with narrow tolerances. The poorer accuracy levels also pose grade problems. To counter this, the conventional practice has been to tunnel larger casings and then install product pipes within the casings at the required grades. Due to precise installations through this hybrid method, the contractors can use smaller casings and hence save on the casing costs (Anderson 2008).

PTMT-HDD

Plastic pipes such as PVC and HDPE could not be used with conventional PTMT because of their low compressive strengths. However, due to their high tensile strengths they are extensively used with HDD that pulls the product pipe into place. The need for installing such pipe materials accurately on line and grade has led to the development of PTMT-HDD hybrid method. The first step of this hybrid method is the same as that of the conventional PTMT method. Once the pilot bore has been completed, the PTMT machine is removed from the jacking shaft and replaced with a HDD drill rig. The drill rods of the HDD rig push the pilot tubes into the reception shaft where they are removed. Once the drill rods reach the reception shaft, a reamer head trailed by a pre-welded chain of HDPE pipes is attached to the first section of the drill chain. The HDD rigs then pulls the HDPE pipe chain into the pilot tube tunnel. This hybrid method is typically used with water pipelines.

PTMT-Pipe Ramming

The PTMT-Pipe Ramming hybrid method is used to add the guided tunneling component to the otherwise relatively inaccurate pipe ramming technology. The first step in this method is the same as that of the conventional PTMT method. A PTMT machine is attached to the pipe ramming rails using a special set of adapters. After the pilot tube boring is completed successfully, the PTMT machine is removed from the jacking shaft and replaced by a pipe ramming machine. A reamer, trailed by casing pipe, is attached to the last section of the pilot tube. Steel casings are tunneled into place by the pipe ramming equipment while the pilot tubes are retrieved from the reception shaft. After the steel casings replace all the pilot tubes, augers remove spoils collected inside the casings.

2.4 Advantages and Limitations of PTMT

PTMT is best suited in congested urban settings, where applicable, compared to open trench method and other similar trenchless methods such as microtunneling and auger boring. The guided boring machines used for PTMT are compact, compared to other trenchless technologies, thereby requiring smaller surface lay down areas and smaller shafts. This minimizes the social costs and disturbance to vehicular and pedestrian movement. Also PTMT is inexpensive and less technology intensive when compared to microtunneling (Abbott 2005). PTMT can perform well in soils below the water well, though it has some limitation when dense sands are encountered. As previously discussed, using open trench method in such conditions may be expensive. PTMT can also be used for exploratory work before casings or product pipes are installed. Abandoning pilot tubes inside the ground is a cheaper option when compared to loss of productivity, time and loss of expensive casings or product pipe upon a drive of main installations being abandoned due to unforeseen circumstances (Anderson 2008).

Today’s urban underground environments are congested and often require new pipe installations within close tolerances to existing infrastructure. Considering the high levels of grade and line accuracy associated with PTMT, it is possible to install pipes with close clearances to existing utilities. As an example, PTMT method was successfully used to install a waterline within 3 feet of a gas line on a project in Alaska (Ramos and Stephl 2008). Another advantage of PTMT is that the technology offers the same level of accuracy as microtunneling at significantly lesser costs (Haslinger et. al. 2007). However, PTMT is not very effective compared to microtunneling, when installing in cobbles.

Even a slight condensation in the optical path (pilot tube cavity) may result in problems to the guidance system. Setting up and flushing the pilot tube cavity using a dry inert gas might delay production and add to the cost of installation. Further, the technology as it is can only be used in select soil conditions as seen from Table 2. Additional equipment such as air hammers are required when installing in tough grounds like rocks, marls and chalks. PTMT, like auger boring, being an open-face tunnel technology may require additional efforts to control flowing ground when installing below the ground water level (Gelinas et. al. 2010).

2.5 Case Studies

This section presents three case studies of different projects on which PTMT methods were used. The following case studies highlight projects' successes with PTMT, advantages of the technology, importance of geotechnical information and the use of various method of PTMT, among other subjects.

2.5.1 City of Bloomington Project (Force et. al. 2005)

This case study demonstrates the reasons for the selection of Pilot tube microtunneling (PTMT) over open trench method and other trenchless technologies. The case study also highlights the importance of proper geotechnical investigation when using trenchless technologies in general and PTMT in particular. The project under discussion is owned by "The City of Bloomington", Minnesota. This is a sewer construction project around the Mall of America, to allow for large scale commercial expansion around the mall. The selected layout for the sewer required the installation of 2,074 feet of 18 inch clay sanitary sewer pipe, 150 feet of 36 inch steel casing, 168 feet of 18 inch restrained joint DIP sanitary sewer pipe, and seven new manholes.

There were many factors controlling the choice and the method of construction such as significant construction activity was to take place during the Christmas holiday season of 2003, but the infrastructure above the proposed pipeline was very congested and disruption to the businesses and public was not desired by the city. Other factors that dictated the selection of an appropriate construction method were unfavorable Minnesota's weather conditions in the winter, limited right of ways, close proximity to existing utilities and geology. The geotechnical report identified the existence of a high water table as a primary risk. The geotechnical evaluation also identified poorly graded sand commonly at many test bore holes along the layout of the proposed sewer.

Open trench construction was ruled out considering the space limitations, potential disruption to businesses and prevailing geotechnical conditions. The engineers initially proposed microtunneling or an approved alternate trenchless method for the construction. The limited right of ways demanded the reception and jacking shafts to be as small as possible. The contractor proposed PTMT as the alternate method and finally the owner issued an addendum authorizing microtunneling and PTMT as the only acceptable methods for construction. PTMT was selected primarily for the small sizes of shafts required and accuracy offered by the technology in terms of line and grade allowing installations at close tolerances to existing utilities. Also, the technology's capability of performing well under groundwater conditions, with the exception of dense sands, favored its selection. While microtunneling is a capable method in the investigated geotechnical conditions, it was not selected considering the high costs associated with the technology and large surface footprint requirements. The project was awarded to ECI Inc. The contractor used the two-step PTMT method for the installation. The construction began on October 20, 2003 and was complete on April 8, 2004. A total of 10 round shafts were dug. The jacking shafts measured 8 foot in diameter, while the receiving shafts placed had a diameter of 6 foot.

The project encountered many unforeseen geotechnical conditions during the course of construction. The geotechnical reports provided by the designer and the owner at the beginning stages of the project were later discovered to be incomplete and inaccurate. While the geotechnical report made no mention of the presence of cobbles along the layout, they were frequently encountered forcing the installation to be stopped midway on several occasions. Remedy methods such as replacing the reaming head with a cutting head also proved futile as the auger casings were clogged with cobbles of large sizes. In one of the drives, the drill encountered cobbles which built up in front of the reaming head preventing the augers from transporting excavated material back to the reception shaft. This resulted in an increased mass build up in front of the reaming head and thereby significantly increasing the required jacking forces. The drive had to be stopped when the required jacking pressure reached the capacity of the jacking frame of 100 tons.

The tooling trapped inside the earth from stopped drives could not be excavated until the holiday season was over, thereby forcing the contractor to uncouple the jacking frames from the failed drives and work on the new drives. This put significant strain on the contractor to source new tooling and expedite the work progress to meet deadlines. Microtunneling or other trenchless methods that can efficiently handle installation in cobbles could not be used when PTMT failed, because the sizes of the compact shafts that were already in place would not fit their requirements. Though the project completed nearly on the anticipated time, the project budget doubled. Therefore it is imperative to have good geotechnical information before a suitable trenchless technology is selected or work is commenced. Especially when using PTMT, a proper investigation should be made over the sizes of cobbles possibly encountered.

The project encountered a problem with the optical guidance system initially. This was due to the condensation of air inside the pilot tubes which caused sight problems in the optical cavity. The crew used extra dry nitrogen to flush out the pilot tubes and it worked well. Installation on one of the drives was halted for a brief while when the temperature reached minus 30 degree Fahrenheit. The benotine lubrication system and the hydraulics froze at this temperature. The project also faced some issues with faulty equipment resulting in installation delays.

The many unforeseen conditions encountered, resulted in extra costs and burden on the contractor. The jacking system chosen based on inaccurate geotechnical investigation, could not perform in the unanticipated ground conditions. The owner recognized the change of geologic conditions and processed change order to that effect. This case study highlights the importance of thorough and comprehensive geotechnical investigation, for the proper selection of the methods and equipment, and also to the overall potential success of the project.

2.5.2 Two Projects using PTMT-HDD Hybrid Methods (Ramos 2009)

This case study demonstrates the methodologies of two projects that used PTMT in conjunction with HDD for the installation of water pipelines. This hybrid method is capable of installing water pipelines, at high accuracy in line and grade, using plastic pipes which are otherwise impossible to install using traditional PTMT. The hybrid method involves drilling a pilot bore, precisely on line and grade, using a PTMT machine as the first step. Once the pilot bore is complete, the product pipe is installed along the centerline of the pilot bore using the reaming and pull-back processes similar to HDD. The contractor on both the projects was Trenchless Construction Services based in Arlington, Washington. Lessons learned from one project were used for the success of the other project.

The first project based in Washington state involved installation of 1000 feet of 10 inch HDPE gravity sewer. The project was initially started as open trench, however trenchless methods were sought for the final stretch as it was proving very difficult to install via open trench in the dry running sands. The contractor proposed to use a hybrid of PTMT and HDD methods for this project as well. As a first step, the pilot tube unit was placed in a 10 foot by 20 foot jacking shaft and boring was begun. Pilot bore drives varied from 300 to 350 feet. Once the pilot bore was complete, the PTMT machine was removed from the jacking shaft and replaced with a HDD rig. The HDD drill rods then pushed out the pilot tubes into the reception shaft. Once the drill rods reached the reception shaft, a steering head was attached to the drill rods and a curve bore was drilled to the surface. A 14 inch reamer was attached to the drill rods after it broke at the surface. The other end of the reamer was attached to a swivel that was trailed by a pulling head.

A continuous HDPE pipe was pre-welded to the pulling head and the pull back operation was started. Drilling mud was used during the reaming and pullback operation to remove spoils. The installation of one drive was complete when the HDPE pipe was pulled back from the reception shaft to the jacking shaft. After completion of a drive, the HDD drill rig was replaced with the PTMT machine to complete a drive in the opposite direction. After pilot boring on the second drive was complete, the PTMT machine in the jacking shaft was again replaced with the HDD drill to perform the pull back operation. This operation cycle was tedious as the respective equipment for PTMT and HDD had to be replaced each time.

The second project, located in Alaska, involved installation of over 1100 feet of 8 inch water line in a severely congested underground environment. Due to the high accuracy offered by PTMT in line and grade, the designer therefore recommended the technology which was later modified by the contractor. The contractor proposed a hybrid of PTMT and HDD, primarily because this method would be able to install HDPE pipe. HDPE pipes, mostly used for the water line possess low compressive strengths thereby eliminating their use with jacking technologies such as PTMT. The pipe was to be installed beneath a narrow drive way at a depth of 10 to 11 feet in gravely soils and the main right of way for homes in that area had four below-grade utilities. Because of the congested environment, both above and below the ground, and also due to utility and service lines observed, trenchless methods were sought over open trench construction. PTMT was selected over its peers largely because of the congested construction environment which demanded installations at high precision. HDD was originally considered to replace the existing water line but the existing soil conditions rendered HDD method as non-feasible.

The lessons learned in the Washington project were incorporated in the Alaska project especially into the equipment setup and layout. For example, the Washington project revealed that initiating the bend from the reception pit to the surface may result in a long distance from the pit to the surface. Also it was learned that placing the drill rig inside the jacking shaft was not advisable as all the ancillary equipment would have to run down to the rig from the surface. The Alaska project, instead, placed the HDD rig near the reception shaft. A sloped path from the rig to the reception shaft was open trench by the contractor as the depth of the installation was only 10 feet. Once the first step of pilot boring was complete, the drill rods pushed the pilot tubes back into the jacking shaft. Pull back operation was performed from the jacking shaft to the reception shaft. One drive was complete when HDPE pipe was installed on the particular section. After completion of a drive, the PTMT machine was turned inside the jacking shaft to initiate pilot boring in the opposite direction for the next drive. PTMT machine had to be moved only once for two drives, while the HDD rig positioned on the surface could be easily moved after each drive. This work structure heavily reduced the set up times for each drive.

The two projects demonstrated the various advantages of using the PTMT-HDD hybrid method. HDPE pipe that can otherwise not be installed with PTMT could be installed using this method at high precision. PTMT, when compared to HDD, is a time taking method in having to push the casings and then replace the casings with product pipe sections. This hybrid method extracts the best from both the technologies: expanded pipe options, faster installation, high line and grade control. The case study demonstrated an efficient work layout for using this hybrid method.

2.5.3 St. Louis Project (Sewing et. al. 2009)

This case study addresses the following areas: selection of PTMT over other trenchless technologies, the use of powered heads for installing large diameter pipes in tough soil conditions, the importance of geotechnical investigation. The current PTMT project for the Metropolitan St. Louis Sewer District (MSD) required installation of approximately 1,900 feet of 18-inch and 45 feet of 8 inch gravity sanitary sewer up to a depth of 23 feet. The proposed pipeline was located under the parking lot of a major mall and crossed a busy street. There were many utilities that ran in close tolerances to the proposed alignment. Trenchless methods were chosen over open trench construction primarily to minimize the interruption caused to traffic flow, to provide safe work zones around the mall, and to not disturb the utilities that service the mall. PTMT was chosen over its peer trenchless methods as the jacking and reception shafts required by PTMT are much smaller compared to the other methods. Also, lesser on-surface space requirements and suitability for the pipe diameter to be installed favored the selection of PTMT.

The 8 inch diameter pipe was installed using the conventional three-step PTMT method. The 18 inch diameter pipe was installed using the modified three-step method where a powered cutting head (PCH) was used. This method was selected as the geotechnical evaluation indicated the presence of large diameter gravels, hard clays and shales. The final pipeline was installed at an accuracy of $3/8^{th}$ inch or better in line and grade. Extreme care was taken during the design phases to align the pipeline so as to avoid existing underground utilities, underground structures and unsuitable soil conditions. Aerials and contour drawings from over 40 years were studied in this process. A through geotechnical investigation was performed to determine the characteristics of the soils. A total of 17 borings were drilled along the alignment of the proposed pipeline and soil samples were collected at various depths. The soil samples encountered were mostly silty clay or clay mixed with gravel.

Both the diameter installations used standard pilot tubes and 11 inch outside diameter auger casings for the first and second steps, as in a conventional three-step PTMT method. For the 8 inch diameter pipe, the crew used the conventional three-step method of replacing the casings with the product pipe. However, for the 18 inch diameter pipe installation a PCH was used to cut through the ground followed by the product pipe installation. PCH reamed the bore hole further to match the outside diameter of the product pipe. This project had been successfully executed with the use of PCH, which would have been otherwise very difficult to install in the tough soil conditions.

The final cost on this project slightly exceeded the initial estimate. The cost increase was due to the presence of gravels and cobbles for over 50% of the total project length of the 18 inch diameter pipe. Three concrete piers were encountered during the final drive, which required the need of excavation and removal. This was a significant part of the extra cost. The presence of gravels and cobbles slowed down the installation greatly. The project suggested that contractors must consider the geotechnical conditions adherently and bid their PTMT project accordingly. PTMT avoided inconvenience to the traffic flow because of its smaller on-ground space requirement and smaller shafts. This case study demonstrates the successful use of PCH in tough soil conditions. Even though a through subsurface investigation was performed it fell short in identifying some underground structure which resulted in added costs and delays.

CHAPTER 3

SURVEY

The first section of this chapter discusses the techniques used in development, and organization of the survey questionnaire. The next section discusses the results of the compiled data of the survey responses.

3.1 Survey Methodology

A survey of the pilot tube microtunneling (PTMT) industry in North America was developed at Arizona State University, in consultation with equipment manufacturers, industry consultants and contractors working with the technology. Though the technology's methods, applications, capabilities and limitations are well documented, there is little documented literature available on the industry trends, business practices and contractors' perspectives on the technology. The survey was aimed at studying these topics along with the technology's applications and capabilities.

To ensure a higher response rate, the survey was designed to be short. Most of the questions in the survey were designed in a format such that the respondents can readily answer them without having to browse through project records. For example, some questions in the survey asked for approximate percentage distributions (eg: client types, contractor roles). Yet the survey extracted critical data such as the number of PTMT projects completed by the contractors, amongst other trenchless technologies, between 2006 and 2010. This information was critical in generating industry trends, as it was used to calculate weighted averages from the contractor's responses to some other questions.

The questions in the survey were organized under three sections. The first section contained questions related to the contractor's business activities and experience with PTMT among other trenchless technologies. In the second section contractors were asked to provide information on work solicitation/contractual practices, types of project undertaken and their experience with different pipe materials, diameters. The final section addressed project planning, risk considerations and the use of different variants of the technology. The survey is included in Appendix A.

A list of PTMT contractors was put together in consultation with major equipment manufacturers and industry consultants. The Del E. Webb School of Construction at Arizona State University started contacting contractors through phone calls, email and mail starting in September 2010. Approximately 110 contractors were contacted. In correspondence with the contractors it was determined that approximately 85 of the 110 contractors actively work with the technology. As on February 2011, 22 questionnaires were returned representing a response rate of approximately 26%. The response rate for this study is comparable to the response rate of 31% for a similar survey conducted by Allouche et. al. (2000) for the Horizontal Directional Drilling (HDD) industry.

The responses were diverse in terms of company size, geographic location, geological conditions and experience with PTMT. It was observed that a majority of PTMT contractors also pursued other trenchless technologies. A total of 20 responses were obtained from contractors in the United States, and 2 were from Canada. Questions 4 and 5 from Part 2 of the survey, that were aimed at extracting data related to the contractors' experience with different pipe materials, were left out from the analysis as they failed to gather enough responses. This is mostly probably due to the effort needed in answering them. Barring these two questions, the rest of the questions could be readily answered and the response rate was expectedly very high.

The individual survey responses are kept in strict confidence and the same was communicated to the contractors. This study makes use of only compiled information with no individual data being attached with any respondent. A list of the contractors that participated in this study is presented in Appendix B.

3.2 Results

The results presented in this Chapter are based on survey responses from 22 contractors, henceforth referred to as the contractors, working with pilot tube microtunneling among other trenchless technologies. The respondents have a combined experience of 450 pilot tube microtunneling (PTMT) projects among a total of 5,770 trenchless projects completed between 2006 and 2010. The data provided by the respondents was cohesive with the general trends in the Trenchless industry. The respondents were asked to provide data in the form of percentages for some questions, for example the client types such as private clients, city, state and federal governments. These percentages were then multiplied with their individual number of PTMT projects to calculate weighted averages.

The number of projects completed during the surveyed period, 2006 to 2010, varied considerably from contractor to contractor. Therefore it is likely that the analysis for some of the survey aspects, that considered the number of projects to extract trends, could be favorably inclined towards the results provided by the bigger contractors. Therefore, where necessary, the data was also analyzed by considering the number of respondents responding in favor of a particular trend in addition to the analysis based on the total number of projects towards the trend. As previously noted questions 4 and 5 from Part 2 of the survey (see Appendix A) were not considered for analysis as most of the survey responses did not provide quantifiable data for these questions.

3.2.1 Company Profile

This section presents analysis of the information provided by the respondents in Part 1 of the survey questionnaire titled company profile. Part 1 of the questionnaire aimed at gathering general company data regarding the areas of activity, experience with PTMT, breakdown of the number of projects completed using various trenchless technologies between 2006 and 2010, their role on the projects, client types and ownership of equipment.

Areas of Activity

Surveys responses were obtained from across United States and Canada. Of the 22 surveys that were returned, 20 were from the United States and two were from Canada. A map of the North American continent showing the areas of activity of the respondents is presented as Figure 18. A state or province was identified as an area of activity if the responding contractor had completed a PTMT project in that location. The respondents together had worked in 28 of the 50 US States, and in three Canadian provinces. There was also one contractor with international experience of working in Vietnam on a Military project. It could be observed from Figure 18 that this analysis is based on a good geographical spread including all major US and Canada divisions except for the Northeastern United States. Among the respondents, California had the highest presence with 3 contractors followed by Arizona, Colorado, Illinois, Maryland, Minnesota, Ohio, Virginia, Washington, Wisconsin and Wyoming with 2 contractors each. Florida, Georgia, Hawaii, Indiana, Iowa, Kentucky, Missouri, Nebraska, Nevada, North Dakota, Oregon, Pennsylvania, South Dakota, Texas, Utah and West Virginia, were represented by one contractor each. Both the respondents from Canada that participated in this research have worked in the provinces of British Columbia, Alberta and Saskatchewan. Thirteen of the 22 respondents have worked in multiples territories, with one particular contractor working in as many as 6 states and another contractor in 5 states.

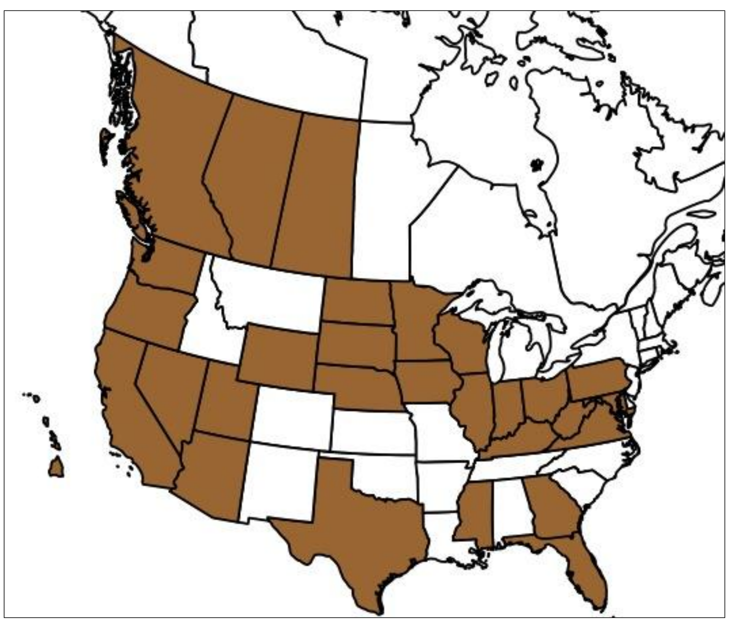

FIGURE 18. Areas of Activity by Survey Respondents

Experience with PTMT

The respondents were a diverse mix in terms of their experience with the technology. The respondents' experience with PTMT ranged from two to 11 years. Five of the 22 respondents have been using the technology for 8 years or more, with three respondents having an experience of 10 or more years with the technology. This is a significant point of interest as PTMT was introduced in the US only within the last 15 years. Over 50% of the respondents have started using the technology within the last 5 years showing the increasing prominence and awareness of PTMT among the trenchless community. This statement could further be substantiated by the fact that over 25% of the respondents have adopted PTMT within the last 3 years, despite the prevailing adverse market conditions. A majority of the new entrants had been previously working with and still continue to work with other trenchless technologies, primarily auger boring.

Comparative Standing among Contemporary Trenchless Technologies

It is common in the trenchless industry for contractors to provide services with more than one technology. Keeping with the trend, PTMT contractors provide services with other trenchless technologies such as: Auger Boring, Horizontal Directional Drilling (HDD), Microtunneling, Pipe Jacking and Pipe Ramming. Only one of the respondents was solely dedicated to PTMT technology. PTMT is similar in many ways to auger boring. However, as previously discussed PTMT installations are highly accurate with line and grade precision owing to its guidance system. The similarity in methodologies is well reflected in the trend that 80% of the respondents also work with auger boring. It was observed that a majority of the PTMT contractors have been traditional Auger boring contractors. PTMT is also slightly similar to pipe jacking and pipe ramming in the boring methodology. Seventy percent of the respondents are experienced with pipe jacking while a little over 50% of the respondents work with pipe ramming. HDD, though very different in methodology and equipment from PTMT, is used by about 45% of the respondents. It is to be noted that though PTMT originated from microtunneling, only 30% of the surveyed contractors have experience with the latter technology. One of the major disadvantages of microtunneling is the higher capital cost to procure the necessary equipment (Jung and Sinha 2007). Therefore it could be inferred that only a few contractors are in a position to provide services using this technology.

Table 3 presents the total number of projects executed by the respondents using various trenchless technologies between 2006 and 2010. The table also presents the percentage of projects executed by each technology, among total trenchless projects, for the particular years. The data has been presented in a stack chart in Figure 19. The respondents executed a total of 450 PTMT projects out of a total of 5770 trenchless projects undertaken, representing a share of 7.8% of all projects completed. It should be noted that auger boring projects comprised 53% of the total projects completed. This figure reaffirms that many of the contractors pursuing PTMT had traditionally been auger boring contractors. Microtunneling projects formed only 1% of the total trenchless projects surveyed. The total number of projects, executed by the respondents, combining all the technologies slightly increased from 2006 to 2007 followed by a steady decline in the following years. A decline of 33% in the total number of projects completed by the respondents between 2007 and 2010 reflects the prevalent economic scenario.

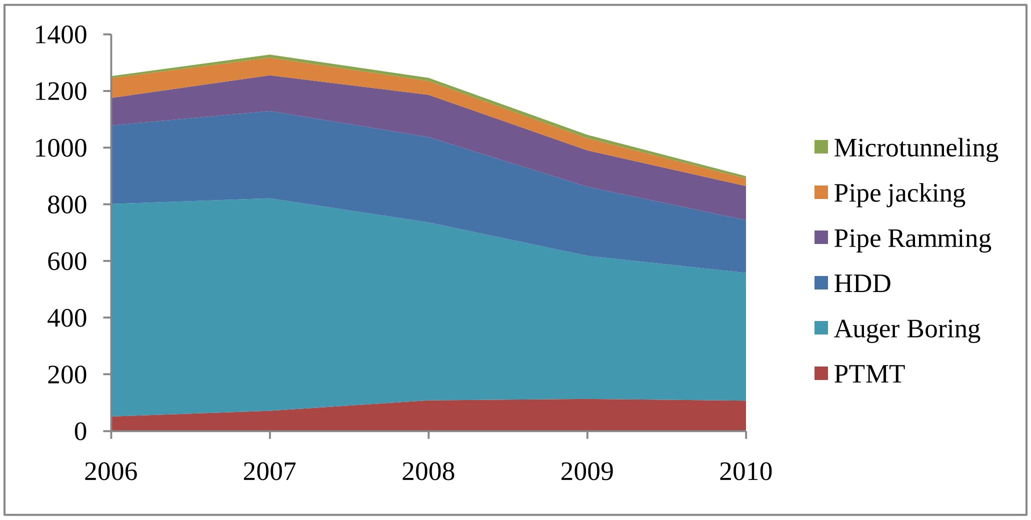

FIGURE 19. Share of Trenchless Project Executed by Various Technologies

Auger boring and Pipe jacking projects completed by the respondents witnessed a decline of 40% and 61% respectively in the period 2006 to 2010. However, it could be observed that PTMT had witnessed steady growth in the same period. The number of PTMT projects executed by the respondents increased from 51 in 2006 to 107 in 2010 indicating a growth rate of 110% over the five year period. It can be noted from Table 3 that while the percentage share of auger boring projects, among the respondents, steadily decreased between 2006 and 2010, PTMT witnessed a significant growth during the same period. This could suggest a possible trend that PTMT is replacing some of the auger boring projects, where applicable, as awareness of the technology’s advantages is increasing. Within its range of soil conditions and diameters, PTMT can offer high levels of accuracy at comparable costs with respect to auger boring.

TABLE 3. Distribution of the Projects Executed by the Respondents Using Various Technologies between the Years 2006 and 2010

Technology	Number of Projects (Percentage share)						Growth/Decline between 2006 and 2010
	Year					Total	
	2006	2007	2008	2009	2010		
PTMT	51 (4%)	71 (5%)	108 (9%)	113 (11%)	107 (12%)	450 (8%)	110%
HDD	277 (22%)	308 (23%)	301 (24%)	244 (23%)	186 (21%)	1316 (23%)	-33%
Microtunneling	7 (1%)	11 (1%)	11 (1%)	12 (1%)	8 (1%)	49 (1%)	14%
Pipe Ramming	97 (8%)	126 (9%)	149 (12%)	128 (12%)	120 (13%)	620 (11%)	24%
Auger Boring	750 (60%)	750 (56%)	628 (50%)	505 (48%)	451 (50%)	3084 (53%)	-40%
Pipe jacking	70 (6%)	62 (5%)	49 (4%)	43 (4%)	27 (3%)	251 (4%)	-61%
Total	1252 (100%)	1328 (100%)	1246 (100%)	1045 (100%)	899 (100%)	5770 (100%)	-28%

Table 4 provides a distribution of the share of PTMT projects among the trenchless projects portfolio of the respondents. It could be observed from Table 4 that for a majority of the respondents, PTMT formed less than 25% of their total trenchless project load. This figure reiterates the fact that a majority of the contractors work with other technologies for considerable part of their work load.

TABLE 4. Distribution of the Respondents by their Individual Share of PTMT Projects

Share of PTMT Projects	Respondents	
	Count	Percentage
0-25%	16	73%
25-50%	4	18%
50-75%	1	5%
75-100%	1	5%
Total	22	100%

Clients and Contractor Roles

The contractors were asked to provide a percentage breakup for their PTMT clients in the four categories: city or municipal governments, state or provincial governments, federal government and private clients. It was observed that city and municipal governments provide the largest number of PTMT projects with a share of 43.8%. The high percentage for this type may be because a majority of the water and sewer projects, which form a significant portion of PTMT projects, are controlled by city and municipal governments. Private clients formed the next biggest set with a share of 39.1%. Federal and State governments had a share of 3.4% and 13.7% respectively. As seen from Table 5, nearly 60% of the respondents indicated that they obtained over half of their PTMT projects from city and municipal governments. Although projects from private clients form nearly 40% of all PTMT projects surveyed, 55% of the respondents indicated that they obtained less than 25% of their PTMT projects from this type of clients. The high percentage for PTMT projects from private clients is because of the presence of two large contractors in the data set that obtain a majority of their work from such parties.

TABLE 5. Distribution of Respondents by Percentage of PTMT Share and Client

PTMT percentage share	Client Type			
	City or Municipal		Private	
	Number of Respondents	Percentage	Number of Respondents	Percentage
0-24%	5	23%	12	55%
25-49%	4	18%	3	14%
50-74%	8	36%	2	9%
75-100%	5	23%	5	23%
Total	22	100%	22	100%

The respondents acted as subcontractors on 80% of the PTMT projects and as general contractors on 20% of the PTMT projects. This data leads to the conclusion that a majority of the PTMT projects are parts of larger utility projects rather than independent installations. There have been many PTMT case studies where parts of the project requiring higher levels of accuracy and under tight space constraints are executed with PTMT, while other sections completed with either open trench method or other trenchless technologies. As seen from Table 6, 73% of the contractors indicated that they acted as general contractors on less than 25% of the projects. Eighty two percent of the contractors indicated that they acted as subcontractors on at least 75% of their PTMT projects.

TABLE 6. Distribution of Respondents by Their Role on PTMT Projects

Percentage of PTMT projects	Role on the project			
	General Contractor		Subcontractor	
	Number of Respondents	Percentage	Number of Respondents	Percentage
0-24%	16	73%	4	18%
25-49%	2	9%	0	0%
50-74%	0	0%	0	0%
75-100%	4	18%	18	82%
Total	22	100%	22	100%

Equipment

Jacking frames manufacturers characterize their product line primarily using two parameters: tonnage and install diameter range. For the purpose of this research, the jacking frames for PTMT had been divided into 5 categories basing on the diameter ranges they can install. The 22 respondents together owned 46 jacking frames. As seen from Table 7, approximately 55% of the respondents owned more than one jacking frame. The highest number of frames owned by a single contractor was 7. The data suggested that 18% of the respondents do not own any jacking frames despite completing PTMT projects. The survey indicated that 20% of the frames were 12 inch or less, 37% up to 25inch, 26% up to 38 inch, 13% up to 51 inch, and only 4% greater than 52 inch, in diameter. Figure 20 demonstrates the distribution of jacking frames among the surveyed contractors. The data suggested that some respondents owned a large inventory of frames compared to their number of PTMT projects, while some respondents owned fewer frames in comparison to their PTMT work load. However these abnormalities are nullified by the fact that they either have worked on a large number of auger boring projects or might own a large inventory of auger frames. This conclusion cements the fact that auger boring and PTMT frames are used interchangeably on projects.

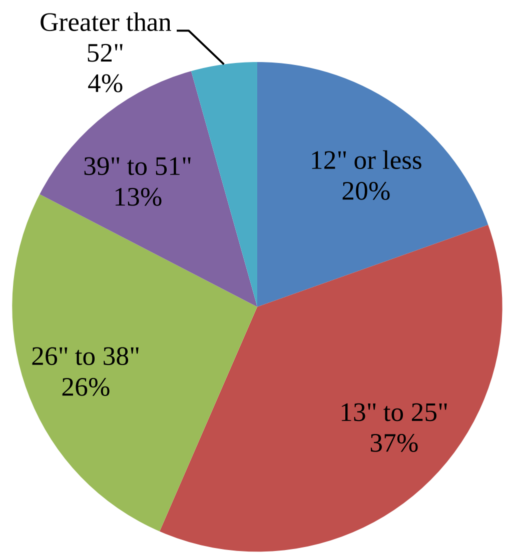

FIGURE 20. Distribution of the Jacking Machines Owned by the Respondents

TABLE 7. Distribution of the Respondents by ownership of Jacking Frames

Number of frames owned	Number of contractors	Percentage
0	4	18%
1	6	27%
2	5	23%
3	2	9%
4	3	14%
5 and above	2	9%
Total	22	100%

Approximately 20% of the respondents indicated that they had utilized rented PTMT machines or frames, and 32% had utilized rented equipment or tubes. As previously noted, 18% of the respondents indicated that they do not own any jacking frames and rent equipment on a need basis. Twenty three percent of the respondents indicated they complete PTMT projects using rented equipment/tubes. In general, if a contactor rented frames or tubes it was done on 100% of their projects. The above mentioned statistics lead to the conclusion that some contractors rent equipment and machines as projects are secured rather than having the equipment residing in their fleet. Contractors routinely rent auger casings on a project need basis. Renting auger casings might be an advantageous strategy as the contractors would be able to install multiple pipe diameters within the range of the jacking frames they own, without having to own any specific set of auger casings. It was observed that there was no direct correlation between the number of PTMT projects completed by the individual respondents and their renting equipment for installations.

3.2.2 Project Characteristics

This section discusses the findings of Part 2 of the survey relating to the typical pilot tube microtunneling (PTMT) projects completed by the respondents. Part 2 of the survey obtained information regarding the type of projects completed, how work is obtained, types of contracts used in the industry, product materials installed, and other trenchless technologies that might be used in conjunction with PTMT methods and equipment.

Project Type

PTMT is capable of installing products for a variety of project types such as sanitary sewer, storm sewer, water, and service laterals installations. Contractors were asked to provide the percentage of their PTMT projects that fell into each of these categories. The percentage provided by each contractor was weighted by the total number of PTMT projects they had completed to obtain the total number of projects completed in each category. It was found that almost 72% of the 450 PTMT projects completed between 2006 and 2010 by the respondents were for sanitary sewers. Storm sewer installations accounted for 14%. As seen from Table 8, 91% of the respondents indicated that sanitary sewer installations accounted for at least 50% of their PTMT projects completed. Fifty percent of the respondents indicated that sanitary sewer projects formed more than 75% of their PTMT work load. Among the large respondents, that had completed over 30 PTMT projects during the period 2006 to 2010, three of the four contractors indicated that sanitary sewer installations form at least 80% of their PTMT work load. Thirty six percent of the respondents indicated that they had not had any experience with storm sewers.

TABLE 8. Breakdown of Work Obtained From Sanitary Sewer Type

Percent of PTMT work	No of contractors	Percentage
<50%	2	9%
50-74	9	41%
75-99	7	32%
100	4	18%
Total	22	100%

Sanitary and storm sewers require precise on-grade installations to maintain flows under gravity. Hence PTMT is a preferred installation method for sewers considering the technology's capability of installing products at high levels of accuracy. On the contrary, drinking/domestic water is pumped under pressure and their installations do not demand the high levels of on-grade precision as required by sanitary and storm sewers. Comprehending this observation water pipe installations provide 9% of the total PTMT projects. Water pipelines are therefore installed by either open trench method or other cost effective trenchless methods such as HDD. HDPE and PVC have traditionally been the preferred materials of choice for water pipelines. These pipes by the virtue of their materials possess high tensile strengths but low compressive strengths. Hence trenchless technologies that involve pushing the product into place are not considered practical for water pipeline installations. Horizontal directional drilling (HDD) that involves pulling the product is extensively used for these installations.

A hybrid method of PTMT and HDD has evolved over the years to leverage the best of both these technologies. This hybrid method has been discussed in detail in Section 2.2.5. As previously stated in Chapter 2, PTMT originated as a method to install small diameter service laterals/house connections. However with rapid improvements in the technology's diameter and drive length range, while at the same time maintaining its higher precision levels, PTMT has evolved to mainstream installations. Currently service laterals form only 5% of the total PTMT installations.

Work Soliciting and Contractual Practices

Competitive bidding, negotiation and contract extension are three most common practices through which contractors obtain work in the construction industry. Contractors were asked to provide a percentage break down of their projects for the three work solicitation practices as mentioned above. These percentages were multiplied to their individual PTMT projects between 2006 and 2010 to calculate the weighted averages. Projects in the trenchless industry are typically obtained through competitive bidding. As an example, Woodroffe and Ariaratnam (2008) pointed out that most projects in the HDD industry are obtained through competitive bidding. On projects involving competitive bidding, the owner hires a design firm for design and engineering work. The owner then solicits contractor services with the design information included in the solicitations. Contracts handed out by public agencies, such as city or provincial governments, typically require awards to lowest responsive and responsible bidders (Edgerton 2008). As previously discussed, contracts from public agencies form a significant portion of the respondents' PTMT work load. Therefore it is expected that competitive bidding type is predominant on PTMT projects. The survey established that 82% of the respondents obtained over 75% of their PTMT projects through a competitive bidding process. Table 9 provides a breakdown for the number of contractors by their percentage share of PTMT projects obtained through competitive bidding.

TABLE 9. Breakdown of PTMT Work Obtained Through Competitive Bidding

Percentage	Number of respondents	Percentage
0-50%	2	9%
50-75%	2	9%
75-100%	18	82%
Total	22	100%

Data provided by the respondents establishes that about 83% of the surveyed PTMT projects are obtained through competitive bidding, while 13% and 4% of the projects are obtained through negotiation and contract extension respectively. Negotiation process is typically used for highly specialized/complicated projects that are executed through a design build approach. In a design build mechanism, the owner hires a firm to execute both design and construction for the projects. A significant advantage of this approach is better coordination of design and constructability aspects of the project.

It is common for large utility companies that have a recurring need for utility construction to establish alliances with selected PTMT contractors. These relationships are usually defined by a contract that extends over an agreed period of time. All of the company's installation needs during the contract period are served by the particular contractors. Such an arrangement is advantageous to the owner as the selected contractors become familiar with the owner's requirements, practices and infrastructure networks. As seen from the data, contract extension type of work solicitation forms only 4% of the PTMT work load among the surveyed projects. It is expected that this number would increase in the coming years as owners are starting to realize the potential and advantages of PTMT.

Often in the trenchless industry, contract type is governed by the risk involved with the project. The data shows that 91% of the respondents had undertaken unit price contract type for their PTMT projects, with 55% of the respondents undertaking unit price contracts exclusively. Unit price method is well suited for utility installation projects (Allouche et. al. 2000). On such projects, typically the parties contractually agree on a set of per foot unit prices. These unit prices vary depending on project parameters such as pipe material, diameter of the product and soil conditions. Within the unit price contract, the contractor executes the installations for the specified lengths at the specified locations and bills the owner in accordance with the quoted unit prices. Such type of contracts may also contain clauses for accommodating change orders in the event of encountering unforeseen conditions. For example, the contractor may request for a change order if the soils report provided by the owner is not accurate.

Lump sum and Lump sum with schedule of unit prices are the next most common types of contracts in the PTMT industry. Twenty five percent of the respondents reported that they had utilized lump sum and 30% reported having utilized lump sum with schedule of unit prices. These contract types are typically used when the scope of the project is very well laid out and the contractors have a good understanding of and confidence in the anticipated project conditions such as other buried infrastructure or soil conditions to be encountered. These contract types are not well suited when the risk factor on the contractors is high.

In cases where the risk borne by the contractor is high, other contract types such as per diem (daily rate), hourly, cost plus fixed fee and cost plus percentage fee are used. These contract types transfer the cost risks from the contractor to the owners. As evident from their names, per diem and hourly contract types compensate the contractors based on the time they spent on the project. For the cost plus percentage fee and cost plus fixed fee contract types, the contractor bills the owner for the entire costs borne on the project in addition to a percentage of that cost or a fixed amount as a fee respectively. None of the respondent had executed PTMT projects in the cost plus fixed fee type. The remaining three contract types had each been undertaken by 5% of the surveyed respondents.

Utilization of PTMT with Other Trenchless Methods

As discussed in section 2.2.5, PTMT is flexible in terms of integrating with HDD, auger boring and pipe ramming. These methods are commonly referred to as hybrid methods. Contractors are able to leverage the best of both the technologies in the hybrid system through such methods. Ninety five percent of the respondents indicated that they had used at least one of the hybrid methods, while 30% indicated that they are experienced with two or more hybrid methods. The high difference among the two figures indicated above is because of the fact that most contractors are only experienced with PTMT-Auger Boring method.

PTMT-Auger Boring is the most widely used method amongst all the hybrids. Eighty five percent of the respondents reported that they had used PTMT in conjunction with auger boring. This figure establishes that PTMT is very flexible in terms of integrating with auger boring. This hybrid method effectively addresses the short comings of both the technologies: poor accuracy levels of auger boring, low jacking capacity of PTMT which limits the diameter of pipe range. This hybrid method has the ability to install large diameter pipes at high levels of accuracy. An accuracy of 0.25 inch over a 500 feet drive could be achieved using the PTMT-Auger Boring hybrid method (Anderson 2008). Additionally, due to similarities between both the technologies the contractors may find it easy to adapt to this hybrid method. According to Akkerman, a leading equipment manufacturer of PTMT boring machines, 54% of all its guided boring machines are currently being used with auger boring applications (UKSTT 2011). PTMT has been used in conjunction with HDD by 25% of the contractors to install water pipelines, whereas 30% of the respondents indicated that they had used PTMT in conjunction with pipe ramming.

3.2.3 Project Planning and Construction Risks

This section discusses the findings of Part 3 of the survey. Questions in Part 3 of the survey obtained information regarding the planning, risk factors, and productivity. Two additional questions were asked at the end of this Part to help define the operational envelope of PTMT installations and identify the contractor's experience with different variants of the technology.

Time Spent on Various Phases of the Project

A typical PTMT project can be organized into four phases namely: planning, site preparation, installation and site restoration. Contractors were asked to provide a break down for the time they spend at various phases of a typical PTMT project. Results as obtained from this analysis are summarized in Table 10. The average times spent on each stage of the project, as calculated by averaging the cumulative data, are as follows: Planning (11%), Site preparation (20%), Installation (59%), Site restoration (11%).

The results reveal that 82% of the respondents spend 10% or less of the total project duration in the planning phase. The remaining respondents reported that they typically spend between 11% and 20% of the project duration for planning. Planning involves activities such as locating the sites for jacking and reception pits, marking the trajectory of the bore and traffic control mapping and setup. City or provincial governments require traffic management plans to be pre-approved before a contractor can start work on the project site. Traffic management is an integral part of utility construction projects as utilities are typically constructed under existing roadways. Where required, contractors hire local firms that specialize in providing traffic management related solutions, including assistance with traffic plan approvals.

TABLE 10. Breakdown of Respondents on Time Spent in Various Project Phases

Percentage of Time Spent	Phase of the Project			
	Planning	Site Preparation	Installation	Site restoration
0-10%	18 (82%)	11 (50%)	0 (0%)	16 (73%)
11-20%	4 (18%)	3 (13%)	1 (5%)	4 (18%)
21-40%	0 (0%)	7 (32%)	5 (22%)	2 (9%)
41-60%	0 (0%)	1 (5%)	7 (32%)	0 (0%)
61-80%	0 (0%)	0 (0%)	4 (18%)	0 (0%)
81-90%	0 (0%)	0 (0%)	4 (18%)	0 (0%)
91-100%	0 (0%)	0 (0%)	1 (5%)	0 (0%)
Total	22 (110%)	22 (100%)	22 (100%)	22 (100%)

The next phase on a PTMT project is site preparation which involves activities such as excavating jacking and reception pits, setting up earth supports/shafts as needed and equipment setup. A major factor affecting the time spent on this phase is the types of soils encountered. When loose soils are encountered, additional processes such as providing water tight shoring for the pits, dewatering, lowering the water levels in the surrounding area, may be required. Time spent on this phase of the project also varies considerably depending on the size of the pits and the number of pits required. In the case of utility projects, it is common for these pits to be converted into manholes post the installation. Hence the number of pits excavated is often governed by the manhole to manhole distance as required by the utility owner. As discussed in Chapter 2, pits are typically 6.5 or 8 feet diameter round shafts, however square or rectangular shafts are not uncommon. The process of pit excavation and shaft setup to support earth loads may be outsourced to a vertical boring contractor. 63% of the respondents indicated that they spend 20% or less of the total project duration on site preparation, while 95% of the contactors reported that they spend 40% or less of the total project duration on the same activity.

The site preparation phase is followed by the installation phase. The activities in the installation phase include boring the pilot hole, replacing the pilot tubes with auger casings and finally replacing the auger casings with the product pipe. This is the most complex phase for any PTMT project. The production rate in this phase of the project is highly project specific and governed by a myriad of factors such as ground conditions, product diameter, equipment reliability and crew experience. More discussion on production rates is presented in the next section. Sixty five percent of the respondents indicated that they spend more than 60% of the total project duration in the installation phase. The minimum time spent in this phase as seen from the data is 30%, while the maximum time is 95% of the total project duration.

The final phase of any PTMT project is site restoration. This phase includes activities such as dismantling of equipment, restoration of pits and, disposal of spoils and environmentally hazardous materials. Seventy three percent of the respondents indicated that they spend 10% or less of the total project duration on site restoration. The remaining respondents reported that they spend between 11% and 20% of the total project duration in this phase.

Project Risks

The contractors were asked to provide ratings on a scale of one to five for the risk associated with certain factors and conditions affecting PTMT installations. The higher rating meant higher risk of the factor/condition affecting project expectations. As the responses are subjective, depending on the perception of the respondent, risk ratings 1 and 2 were categorized under low risk. Risk rating 3 was perceived to be moderate risk while risk ratings 4 and 5 were categorized under high risk. Table 11 summarizes the rankings by factor from highest to lowest perceived project risk, with the tallies of responses and percentage of the total responses for each risk level. Risk ranking was determined by weighting the tallied responses with a weighting of 1 for low risk, 5 for moderate risk, and 10 for high risk. This expanded scale was selected to better illustrate the spread of the perceived risk rankings.

TABLE 11. Risk Factors and Conditions

Risk Factor	Low Risk	Moderate	High Risk	Ranking
Cobbles and Boulders	0 (0%)	2 (9%)	20 (91%)	9.5
Sand and Gravel Soils	6 (27%)	7 (32%)	9 (41%)	6.0
Maintaining Grade	11 (50%)	3 (14%)	8 (36%)	4.8
High Groundwater	10 (46%)	6 (27%)	6 (27%)	4.5
Ground Movements	14 (64%)	7 (32%)	1 (4%)	2.7
Clay and Silty Soils	15 (68%)	5 (23%)	2 (9%)	2.7
Damaging Adjacent Utilities	17 (77%)	3 (14%)	2 (9%)	2.4
Damaging Product Pipe	18 (82%)	2 (9%)	2 (9%)	2.2

Survey results indicated that the risk associated with damaging the product pipe and adjacent utilities during an installation had the lowest risk rankings. Approximately, 82% of the respondents perceived the damaging of the product pipe as a low risk with an overall risk ranking of 2.2. Damage to product pipe may occur from high jacking loads or misaligned joints. However, this situation could be averted, as the jacking frames are equipped with meters that provide readings for the jacking forces. Product pipes could also be damaged by external unanticipated objects such as rocks, buried metal bars and concrete. Jacking loads higher than normal are usually an indication of such geotechnical conditions. On complex projects, PTMT contractors often work with the pipe manufacturers directly to procure pipes of the desired bearing loads that meet the project requirements. Seventy seven percent of the respondents categorized damaging adjacent utilities during installation under low risk while the average risk ranking for this factor of 2.4. Owing to the accurate on-grade and on-line installation capability of PTMT, the chances of damaging known utilities are minimal if installations proceed with sound planning and acceptable tolerances. However, like all other trenchless technologies there is a risk of damaging utilities if they are incorrectly located, unmarked, or unknown.

Ground movements resulting from PTMT installations damaging surface pavements were perceived as a low risk by 64% of the respondents and had an overall risk ranking of 2.7. Unlike some other trenchless methods that rely on displacement of soil, or could cause soil displacement with poor practices, PTMT by its nature significantly reduces the chances of soil displacement or cavity expansion. However, in some soils high jacking forces may result in soil heave, and over excavation of loose soils might result in settlement. The possibility of surface movements increases as large diameter pipes are installed at shallow depths.

High groundwater table was perceived to have a moderate to high risk of affecting PTMT installations and having a risk ranking of 4.5, with approximately 54% of the respondents indicating at least a moderate risk level. Under normal conditions high water table can be controlled with dewatering of soil. However, many cities have strict restrictions in place for performing such actions as it could significantly affect the ground stability in the area. The problems encountered with high ground water table are two-fold: instability of the ground in the jacking/receiving pits and loose soils along the alignment affecting the grade of the installation. In cases of poor soil conditions such as high groundwater table, flowing soils, loose clays, continuous water tight shoring is required all along the excavation to prevent ground movement and potential damage to adjacent utilities (Arbolante et. al. 2005). Concrete pads can be poured at the bottom of the shafts to neutralize ground movements (Fisher 2003) to help proper on-grade installation and provides safe working conditions to the crews working in deep pits.

Though PTMT is generally accepted for its accuracy on line and grade, ground conditions and operator error can lead to variances in alignment. While 50% of the respondents indicated a moderate to high levels of perceived risk, 36% of the respondents indicated it was a high risk, leading to an overall risk ranking of 4.8 for the risk of maintaining proper grade.

The remaining risk factors dealt with soil conditions. The survey asked contractors to provide risk ratings for installations undertaken in clay and silts, sand and gravel, and cobbles and boulders soil conditions. Sixty eight percent of the respondents indicated clay and silty soils were low risk with a risk ranking of 2.7, while sand and gravel had a much higher risk with a ranking of 6.0, and cobbles and boulders had the highest risk ranking with a score of 9.5 and 91% of the respondents indicating it was high risk. While the technology is well applicable in medium to dense sands above the water table, the applicability is marginal in very loose to loose sands above the water table and medium to dense sands below the water table (Boschert 2007). While installations in cobbles up to 100 mm diameter are possible, the applicability of the technology is very limited as the sizes of the cobbles and boulders increase. The problems encountered while installing in cobbles are twofold: grade deviance or stoppage during pilot tube installation and large cobbles getting lodged in the reaming head or auger string.

Factors Affecting Productivity

Contractors were asked to identify factors that affect the productivity of PTMT projects. These responses were reviewed and categorized for discussion as many of the contractors identified common factors. A summary of the results in the form of percentages, for each of the factors reported, is presented in Figure 21. Ground conditions, including soil type and ground water table, received the highest rating with 72% of the contractors reporting it as a major factor. Many did not perceive installation depth, as a major factor as the technology, like many of its counterparts, is capable of working in great depths if the ground conditions permit. Crew experience was reported as one of the major factors by 17% of the contractors. Since PTMT is a highly specialized technology involving an accurate set up of the guidance system, experience level of the crews is crucial.

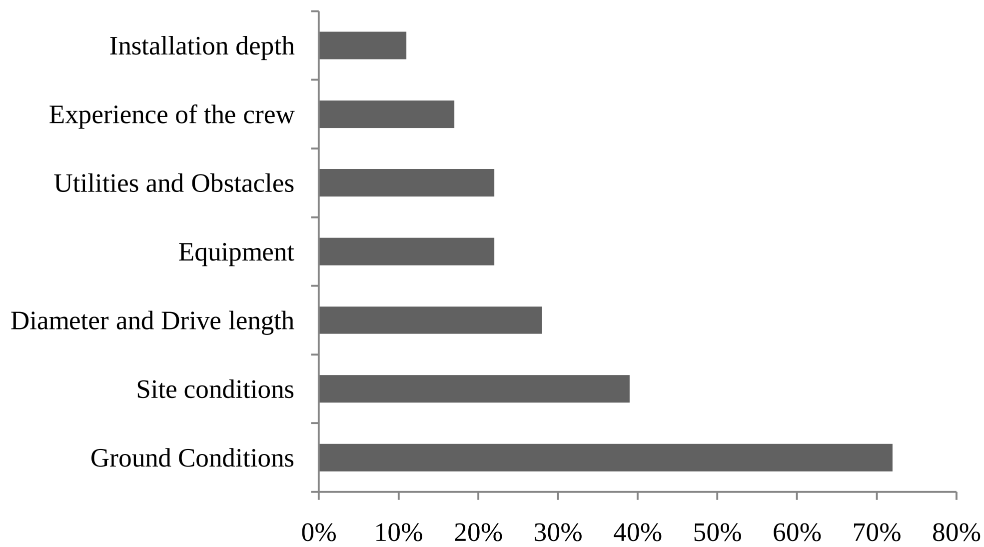

FIGURE 21. Factors Affecting Productivity

Equipment reliability was seen as a major factor by 22% of the contractors. This factor includes considerations such as jacking machines breakdown, inability of the reaming heads to perform in changing soil conditions as the bore progresses. Twenty two percent of the contractors perceived unforeseen utilities and obstacles as a major factor. Site conditions, including traffic control, weather, sizes of shafts, physical area for on-ground equipment, received the second highest rating with 39% of the contractors reporting it as a major factor affecting productivity.

Pipe diameter and drive length received the next highest rating of 28%, among the major factors. As the pipe diameter increases, the contractors may need to perform multiple passes to upgrade the pilot bore diameter for smooth installation of the final product pipe. Also, as previously discussed, as the drive length increases there are chances of condensation in the pilot tube cavity causing the loss of optical vision for the guidance system. Setting up and pumping a dry inert gas to clear the optical path will most likely cause drives to be delayed and increase costs.

Drive Lengths and Pipe Materials

The contractors were asked to provide the longest length they had installed in a single drive with pipes of different materials. Fifty percent of the contractors surveyed reported using vitrified clay pipe on their projects. It was observed that 70% of the contractors that had used PTMT with VCP pipe recorded their longest drive lengths above 300 feet. This is a good indication of the compressive strength of the pipe material. Coupled with other advantages of VCP pipe, including high corrosion resistance and low cost, it is a popular pipe material for PTMT (Haslinger et. al. 2008). Steel pipe was used by 80% of the contractors on at least one of their projects. Seventy percent of the contractors that used steel pipe recorded their longest drives above 400 feet. The longest drive length among the surveyed projects was 550 feet where a contractor used steel pipe. It is likely that some of the projects using steel pipe are large diameter product pipes executed using the PTMT-Auger Boring hybrid method. Only two of the contractors reported installing concrete pipes with PTMT. The longest drive length, as reported by one contractor, using concrete pipes was 502 feet. It is interesting to note that a drive length of 400 feet had been achieved with HDPE pipe using the hybrid PTMT-Horizontal directional drill method.

Pilot Tube Microtunneling Methods

The three main variants of PTMT, as previously discussed, are two phase, three phase and three phase with a powered cutting head (PCH). The results show that 20% of the contractors had used powered head equipment on their projects. Thirty three percent of the contractors were experienced only with the two phase technology while 27% of the contractors were experienced only with three phase. Thirty three percent of the contractors had used both two phase and three phase methods on their projects. Of the total PTMT project surveyed, 51% were two phase projects while 47% were three phase projects. Only 1% of the surveyed projects used powered head equipment. It is interesting to note that while 20% of the contractors had experience with PCH, these projects accounted for only 1% of the total PTMT project surveyed. Basing on this trend, it may be concluded that while the contractors are experienced with the technology, not many projects require the use of powered cutting equipment.

CHAPTER 4

CONCLUSIONS

The traditional method of installing underground pipelines using trenching techniques may be unsafe, time consuming, expensive and disruptive to regular on-ground activities such as vehicular and pedestrian movement. As an alternative to the traditional methods, many new technologies have emerged over the years that minimize the need for trench work. These technologies are together referred to as trenchless technologies. Pilot Tube Microtunneling (PTMT) is a relatively new form of trenchless technology. PTMT was introduced to North America in the mid 1990s and has been emerging as a popular methodology to install gravity sewers accurately on line and grade. Most of the existing literature on PTMT is restricted to project specific case studies and therefore there is an emerging need for further research about the technology.

Contributions made to the field of Pilot Tube Microtunneling through this thesis include:

1) The documentation of the methodology, equipment, practices, applicability, capabilities and limitations associated with this technology through review of existing literature and consultation with industry experts.
2) Analysis of the responses to a survey questionnaire, that was sent out to the practitioners of PTMT across North America, to obtain insights into the industry trends, business practices, risks, and applications of the technology, among other areas.

This research, through the documentation of PTMT methodology and practices, is expected to serve as a good beginning point of reference to academics for further research of the technology. Cities and municipalities may find this research valuable in forming an understanding of the technology, its applicability and risk factors. Contractors working with the technology would find this research helpful in identifying comprehensive industry trends as generated from the survey responses. This information would serve the contractors in positioning and comparing themselves with the practices of the rest of the industry.

4.1 Summary of Survey Results

The results and analysis presented in this thesis were derived from 22 responses to the survey questionnaires that were sent out to contractors that own PTMT equipment and provide services for the installation of underground pipe utilizing PTMT methods. Surveys were returned from a good geographical spread across United States and Canada. The survey respondents together had completed 450 projects using PTMT among 5770 trenchless projects between 2006 and 2010. As revealed by the survey data, PTMT method is well suited for installation of pipe up to 40 inch outside diameter, with drive lengths in the range of 550 feet. Previously available literature on the technology put the drive lengths in 300 feet to 400 feet range.

The respondents were diverse in terms of their experience with PTMT, ranging from two to 11 years. Three respondents had an experience of 10 years and above with the technology. The data revealed that 50% of the respondents had started using PTMT within the last five years, showing the increasing prominence of this technology. However, a majority of the respondents had been providing services with other trenchless technologies for many years. Eighty percent of the respondents indicated that they routinely provide services using auger boring. Auger boring, with a share of 53% among all the trenchless projects completed by the respondents between 2006 and 2010, was the most used method by the contractors. It was observed that for approximately 75% of the respondents PTMT projects formed less than 25% of their total trenchless project portfolio. The data revealed that PTMT projects grew by approximately 110% for the period 2006 to 2010, among the surveyed respondents, despite the adverse economic conditions. This statistic reveals the increasing popularity of this technology.

As suggested by the data, a majority of projects utilizing PTMT were for city or municipal governments. The respondents acted as subcontractors on 80% of the projects completed with PTMT. The respondents together owned 47 jacking frames, with 83% of those rigs being able to install pipes up to 38 inch outside diameter. A majority of the respondents owned between one and two jacking frames. Approximately 20% of the contractors indicated that they do not own any jacking frames, but still provide services with the technology using rented equipment. Eighty six percent of the 450 projects completed using PTMT were for sanitary and storm sewers. Eighty three percent of the projects were obtained using competitive bidding, while 55% of the respondents indicated that they used the unit price contract method on all of their PTMT projects.

While PTMT was designed as an independent installation technology, it acts as a complementary technology to, pipe ramming, auger boring and horizontal directional drilling, in providing an accurate pilot bore for the main installations. PTMT is widely used in conjunction with auger boring, with 85% of the respondents reporting that they had completed at least one project using this hybrid method. Integration of PTMT and HDD expands the technology's pipe material options to using tensile pipes such as PVC and HDPE. Twenty five percent of the respondents indicated that they had used such a method.

Soil conditions were cited as the highest risk associated with PTMT projects, which would be expected for underground construction. The highest risk was encountering cobbles and boulders, followed by sand and gravel soils. These granular soils are very difficult to displace during the pilot tube drilling and can also cause problems when installing casing and removing spoils. Installation in soils with high groundwater table was identified as a moderate risk to high risk. The technology's capabilities are marginal when installing in medium to dense sands below the water table. The lowest risks associated with PTMT were causing damage to the product pipe and damaging adjacent utilities during an installation reaffirming the popularity of PTMT as one of the most accurate trenchless method. Ground conditions were identified by 72% of the contractors as a major factors affecting productivity of PTMT installations. Approximately 40% of the respondents identified site factors, such as traffic control, weather conditions, lay down area, and size of shafts, as a major factor affecting productivity.

As suggested by the data, the most predominantly used pipe materials with PTMT are steel and Vitrified Clay Pipe (VCP). Eighty percent of the contractors reported that they had used steel pipe on at least one of their projects. The longest drive lengths recorded using VCP and steel pipes were 343 feet and 550 feet respectively. A drive length of 400 feet was recorded with HDPE when PTMT was used in conjunction with HDD. Approximately 51% of the total PTMT projects completed by the contractors were executed using the two-step method, while 48% used the three-step method. Powered heads were used on only 1% of the projects.

The pilot tube microtunneling method while relatively new to North America, has seen an increase in utilization between 2006 and 2010, while more traditional methods of trenchless installation have seen a minor decrease in utilization over the same time among the surveyed contractors. This technology is ideal for the installation of pipe on tight line and grade for installation lengths generally utilized between manholes in a municipal setting. As the need to replace buried pipe infrastructure in urban areas increase, it is expected that pilot tube microtunneling will see an increase in utilization due to its highly accurate installations, low impact and small footprint of operation.

4.2 Areas for Future Research

This section presents the author’s recommendations for further research into the area of pilot tube microtunneling.

4.2.1 Practice of PTMT Projects

With the increasing popularity of PTMT coupled with a shortage of documented literature in the area, there is a need for further research into the procedures and guidelines to be used in employing this technology. This research could also include studying the best practices for realizing PTMT installations in an efficient and a sustainable manner. Currently, there are no standard set of PTMT specifications in use by cities and municipalities. Thorough research into the areas of 1) applicability in various soils conditions; 2) pipe materials; 3) diameters; 4) risk factors; 5) drive lengths; 6) ground movements; and 7) appraisal of the variants of the technology, is necessary in establishing industry standards. Development of such specifications may encourage more city and municipal governments to use this technology for their sewer installation needs.

4.2.2 Costs and Productivity

It is felt that there is a need for researching the costs and productivity rates associated with PTMT installations to serve as a reference to the contractors and utility owners in estimating the construction costs and project schedules. A survey may be instituted for this purpose. It is anticipated that the survey developed for this research would serve as a good reference for future industry studies on PTMT. However, it is noticed in consultation with industry experts that contractors might be hesitant in providing cost data as safeguarding their bidding and price information is critical to their future project pursuits. Since most of PTMT installations are for the city and municipal governments, the bidding and project cost data could be available in public domain. However, if this method is employed, it may be challenging to identify project specific factors such as geotechnical conditions, impediments to project success, and unforeseen circumstances, to name a few. Ground conditions, diameter, number of pits/shafts, water table, location of the project to characterize traffic management factors, might be used as variables to categorize projects for analyzing cost and productivity data.

4.2.3 Comparison with Other Methods of Pipe Installation

Cities and muncipal governments now have multiple options in selecting an efficient method for their sewer installation projects. The popular methods for this project type include: 1) microtunneling; 2) auger boring; 3) pilot tube microtunneling; 4) open-trench method. These methodologies widely differ in terms of their applicability, capabilities, and associated costs. Selection of an efficient method based on project specific considerations is crucial for the success of any project. With the advent of PTMT as an efficient, accurate and economical method, within its range of applicability, there is a need for further research to compare this technology with the other applicable methods. A simulation tool may be developed to help the city and municipal governments in selecting an efficient installation method based on variables including, but not limited to: 1) ground conditions; 2) product pipe diameter; 3) pipe material; 4) depth of installation; 5) drive length; 6) project costs; 7) social costs.

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APPENDIX A

SURVEY QUESTIONNAIRE

Part 1: Company Profile

1. List the States and Provinces that you have completed Pilot Tube Microtunneling projects:_______________________________________

2. How many years has your company been using Pilot Tube Microtunneling?:

3. Approximately, how many projects has your company completed over the last 5 years using each of the following technologies:

	2006	2007	2008	2009	2010
Pilot Tube Microtunneling					
Horizontal Directional Drilling					
Microtunneling					
Pipe Ramming					
Auger Boring					
Pipe Jacking					

4. Typical Clients (what % falls under each category):

City or Municipal Government	%
State or Provincial Government	%
Federal Government	%
Private	%

5. Percent of jobs undertaken as a general contractor: _______ %
   Percent of jobs undertaken as a subcontractor: _______ %

6. What sizes of PTMT machines/jacking frames do you own?:

Maximum Installed Pipe Diameter	Number of Units
12" or less	
13" to 25"	
26" to 38"	
39" to 51"	
Greater than 52"	

7. Percent of jobs completed with rented PTMT machines/frames ____ %
   Percent of jobs completed with rented PTMT equipment/tubes _____ %

Contact Information:

Name: ______________________ Email:________________________

Company: ____

All responses will be held in confidence – Contact Info needed to send results of the survey.

Part 2: Project Information

1. Types of PTMT projects undertaken (what % falls under each category):

Water	%
Storm Sewer	%
Sanitary Sewer	%
Service Laterals	%

2. What percentage of your PTMT work is obtained through:

Competitive Bid	%
Negotiation	%
Contract Extension	%

3. Types of PTMT contracts/projects undertaken (Please check all that apply):

☐ Unit Price (rate per foot)
☐ Per Diem (daily rate)
☐ Hourly
☐ Lump Sum
☐ Lump Sum with schedule of unit prices
☐ Cost plus percentage fee
☐ Cost plus fixed fee
☐ Other: ___________________

4. How many projects has your company completed installing the following jacking pipe materials, using PTMT, over the last five years?

	Year				
Material	2006	2007	2008	2009	2010
Vitrified Clay					
Steel					
Concrete					
CCFRM					
Other					

If other – please specify the type of pipe products installed:_______________

5. What length (in feet) of pipe of the following materials did you install using PTMT, in 2009?

Diameter	VCP	Concrete	Steel	CCFRM	Other
8” or less					
10” – 12”					
15” – 21”					
24” – 36”					
Greater than 42”					

6. Do you use Pilot Tube Microtunneling in conjunction with other equipment? Please check the technologies you have used in conjunction with PTMT:

□ Auger Boring	□ Pipe Ramming	□ Directional Drilling

Part 3: Proect Planning and Construction Risks

1. When considering the duration of a project, what percentage of time is spent on the following stages of a PTMT the project:

Planning (Prior to going to site)	%
Site preparation	%
Installation of Pilot Tubes, Casing, and Product Pipe	%
Site Restoration	%

2. Please rate the risk associated with the following factors and conditions:

	Low Risk				High Risk
Damaging adjacent utilities during installations	1	2	3	4	5
Damaging product pipe during installation	1	2	3	4	5
Ground movement damaging surface pavements	1	2	3	4	5
Maintaining proper grade	1	2	3	4	5
High groundwater table	1	2	3	4	5
Installations in sand or gravel soils	1	2	3	4	5
Installations in clay or silt soils	1	2	3	4	5
Cobbles/boulders stopping an installation	1	2	3	4	5

3. Please list some factors that affect productivity on PTMT projects:
   ____
   ____

4. What is the longest drive length that you have installed in a single drive for each of the following types of pipe?

Pipe Material	VCP	Concrete	Steel	CCFRM	Other
Longest Drive Length					

5. Check all the methods of PTMT that you have used, and provide the diameter ranges for each method utilized. Also fill in the percentage of PTMT projects that each of the methods has been used on.

Method	Smallest Diameter	Largest Diameter	% of Projects
□ Two Phase			
□ Three Phase			
□ Three Phase with PCH / PRH			

APPENDIX B

LIST OF RESPONDENTS

1) Aaron Enterprises, Inc., York, PA

2) Armadillo Underground Inc., Salem, OR

3) B Trenchless, Henderson, CO

4) Blevins Road Boring, Hudson, FL

5) Bore Master, Inc., Pewaukee, WI

6) Bradshaw Constrcution Corporation, Elliot City, MD

7) Brannan Construction Company, Denver, CO

8) Calgary Tunneling, Calgary, AB, Canada

9) Claude H. Nix. Construction Co., Inc., Ogden, UT

10) Frank Coluccio Construction, Seattle, WA

11) Kamploops Augering & Boring Ltd., Kamploops, BC, Canada

12) Magnum Tunneling & Boring, LLC., Houston, TX

13) Midwest Mole, Inc., Indianapolis, IN

14) North Core, Fargo, ND

15) Pacific Boring, Inc., Caruthers, CA

16) Riley Contracting, Inc., Norwalk, OH

17) Roddie, Inc., Morgan Hill, CA

18) Specialized Services Co., Phoenix, AZ

19) Super Excavators, Inc., Menomonee falls, WI

20) T&D Trenchless, Murrieta, CA

21) Unknown* (* contractor filled out the survey but did not provide identity)

22) Wayne Arnold Road Boring Co., Smackover, AR